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D12.10 – Foundations of the Theory of Associative Autopoietic Digital Ecosystems: Part 3

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Short Description:

This report is the third in a series of three theoretical deliverables within the OPAALS project (D1.2, D12.1, and D12.10) that aim to develop an integrated theory of associative autopoietic digital ecosystems. The purpose of the theory is to provide a common reference that rationalises and explains (1) the activities of the research community and (2) the process of digital ecosystem adoption as an instrument of sustainable socio-economic development catalysed by ICTs.

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Dependencies:

Achievements*	Done: • Developed a broad and self-consistent meta-theoretical framework that underpins all of digital ecosystems theories and practical activities.. • New insights into inter-epistemological dialogues have been reached in some of the relevant disciplines such as economics. Not done: • The theory itself is partly incomplete, but an emphasis on process alleviates this fact. • The development of a theory of bio-computing is behind the other two disciplinary domains of social science and computer science, so its integration in the overall theory is not discussed explicitly. However, from a philosophical point of view it is not a challenge to do so, which also alleviates this fact.
Work Packages	This work informs all the other WPs of the project and will be circulated among the partners who have not already contributed directly.

Partners	All
Domains	Social Science (to a strong degree), Evolutionary and Interactive Computation (to a lesser degree)
Targets	All project researchers, scientific communities outside the project
Publications*	• Pattanaik, D, Chatterjee, J, and Dini, P (2009). "Dynamism of Organic Assemblage in Digital Ecosystem-Learning and Innovation in DEAL", International ACM Conference on the Management of Emergent Digital Ecosystems, Lyon, 27-30 October, Lyon. Submitted. • Pattanaik, D and Chatterjee, J (2009). "Socio-technical Innovation and the Role of Conversation in a Digital Ecosystem for Agricultural Extension Services in India", Proceedings of the 3rd IEEE DEST 2009 International Conference, Turkey: Istanbul, 4-6 June. • Krause, P, Razavi, A, Moschoyiannis, S & Marinos, A (2009). Stability and Complexity in Digital Ecosystems. IEEE International Conference on Digital Ecosystems and Technologies (IEEE-DEST 2009), Istanbul, Turkey.
PhD Students*	Mehita Iqani (social science)
Outstanding features*	• An innovative synthesis of theoretical and empirical insights in order to build a coherent, and multidisciplinary theoretical framework for digital ecosystems. • New self-consistent ontological, epistemological and methodological meta-theoretical framework that accommodates all of the theoretical and applied perspectives present in digital ecosystems research. • Explicit integration of Popper's and Gidden's perspectives (which were already tacitly present) in digital ecosystems research practice • New research perspective in non-equilibrium economics outlined • Roles of non-linearity and evolutionary behaviour have been clarified and located within the overall framework. • This work has been read and positively evaluated by researchers from the Venezuelan Institute of Scientific Research.
Disciplinary domains of authors*	**Social Science**: Mehita Iqani (LSE), Antonella Passani (T6), Debashis Pattanaik (IITK) **Computer Science**: Sotiris Moschoyiannis (Surrey), Ossi Nykanen (TUT) **Interdisciplinary Natural, Computer, Social Science**: Paolo Dini (LSE)

The information marked with an asterisk (*) is provided in order to address Recommendation n. 4 from the Year 2 review report

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Executive Summary

This report is the third in a series of three theoretical deliverables within the OPAALS project (D1.2, D12.1, and D12.10) that aim to develop an integrated theory of associative autopoietic digital ecosystems. The purpose of the theory is to provide a common reference that justifies and explains (1) the activities of the research community and (2) the process of digital ecosystem adoption as an instrument of sustainable socio-economic development catalysed by ICTs.

The development of such a theory has required considerable work and remains an unfinished project. However, we believe that the general framework is now in place, and it will be easier for new-comers to the digital ecosystems research community to find their way and to contribute productively. The challenge has been to reconcile different epistemological points of view that are unavoidable in as radically interdisciplinary a community such as ours. In fact, the challenge is that rather than undertaking merely interdisciplinary digital ecosystems research, our work is 'inter-epistemological', i.e. it *requires* the integration of different epistemologies. This we have been able to achieve by making recourse to a process model, and by balancing theoretical developments with applications and with empirical input. The main axes of the theory are built on the work of Popper and Giddens. The parts of the theory that are not yet integrated at an *operational* level is a mathematical theory of bio-computing, which is still being developed. However, the role of such a theory within the broader digital ecosystems theory has been resolved at a *philosophical* level as principally a functionalist contribution to enhance the performance and adaptability of the digital infrastructure.

The construction of an integrated theory that spans different disciplines, epistemologies, and methodologies required the development of an abstract 'meta-theoretical' framework that could accommodate the various constituents and understandings of our research whilst remaining consistent with its fundamental structure. Such a framework could not help but be essentially functionalist in character, in the sense that it needed to support the practical execution of research activities requiring the development of a practical theory. As a consequence, our meta-theoretical framework is reductionist to a certain extent. The meta-theoretical framework is presented in the introductory chapter. Chapter 2 presents a fundamental Ontology for digital ecosystems, where we emphasise those ontological categories that, taken together, differentiate digital ecosystems from other socio-technical-economic systems. Chapter 3 takes on the very challenging task of reconciling the different epistemologies upon which our research is based. It does so by proposing a binary meta-epistemological framework where four different dimensions are defined as binary opposites: rationalism/empiricism, objectivism/ subjectivism, collectivism/individualism, and symmetry/context-dependence. Chapters 4 and 5 address the integration of biological and social science perspectives, and of technological and social science perspectives, respectively. Chapter 6 then offers a synthetic process-based theory of an associative autopoietic digital ecosystem, and the process of its adoption.

In order to keep the size of this report manageable, the style of writing is informal and is as self-contained as possible, leaving part of the verification – or falsification – of the hypotheses and claims advanced to future work. However, we have benefited from the experience in digital ecosystems research accumulated over the past 7 years.

The report also includes two appendixes containing a short paper titled "Digital Ecosystems Explained" intended for wide dissemination as well as a glossary of terms unique to the field of research.

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1. INTRODUCTION

As Thomas Kuhn (1996) has explained so eloquently, a community of scientists is a social group, no matter what brand of science they may be studying. Thus, social science has something to say about the structure and behaviour of such a group, and social science concepts such as power relationships and the extent of collaborative behaviour will have an impact on their object of study, whatever it may be. Conversely, as pointed out by Anthony Giddens (1984), the study of social systems is hampered by the fact that, in this case, the 'objects of study' have their own opinions about what is being said about them – in fact, usually as many opinions as there are individuals. Try as we may, therefore, it appears to be impossible to develop a theory of *anything* that is not reflexive in some way, i.e. that does not acknowledge the role of the individuals involved directly or indirectly in the construction of the theory. This indicates a certain level of asymmetry in the theoretical landscape, since social science would appear to be 'more equal' than the other sciences, or 'more fundamental' in this particular way.

In the present case our objective is to develop a theory of digital ecosystems. Even though we will discuss different ways in which the concept of digital ecosystem can be defined in the next chapter, we can already establish that a theory of digital ecosystems is not a general theory of social systems, or a general theory of computation, or a general theory of biology. We can assume that some basic elements of the discussion and some basic constructs in these different intellectual and experiential domains already exist. For example, our theory may help answer questions such as "What makes a socio-technical and economic system a digital ecosystem?" or "What makes an artificial life system a digital ecosystem?" and so forth. As long as this is clear, we will not be afraid to explore some rather deep theoretical and meta-theoretical questions in and around all these domains. We hope this will not cause alarm to audiences who are interested in the practical objectives of digital ecosystems research, of which the most prominent is sustainable socio-economic development catalysed by information and communication technologies (ICTs). We need to explore some deep philosophical questions because we wish to develop a theory that is self-consistent and extensible, and that can accommodate the many different epistemological positions that populate digital ecosystems research communities.

We have thus found a way to address the above conundrums in the context of digital ecosystems research by prioritising the *applicability* of the theoretical choices. This has led to a generalisation of the *functionalist* meta-research framework inspired by the mathematical biologist Robert Rosen (1991) and expressed in category theory notation that was introduced in D12.1 (Botto et al., 2008). Specifically, as shown in Figure 1.1, by associating Aristotelean causal categories to three of the main branches of philosophy, we realised that we only needed to add "empirical feedback" to achieve a process-based meta-theoretical framework that is consistent with the approach we have always followed and with the theory to be described in this report, at all levels of abstraction or detail.

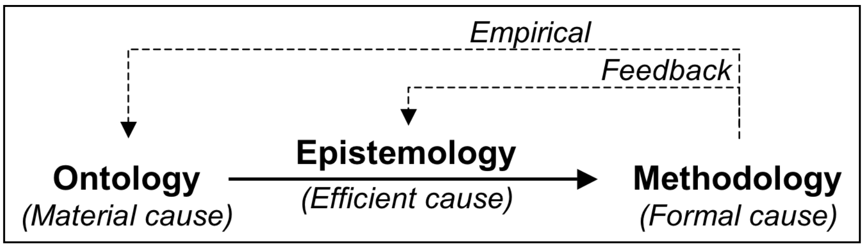

Figure 1.1: Meta-theoretical framework for digital ecosystems

A proper justification of this simple schema would require an in-depth study in the history of philosophy, for which we do not have time or space in this report. This figure should be taken only as a loose and intuitive 'process framework' whose main advantage is to allow for the coexistence of the different epistemologies present in the project, whilst leveraging a shared methodological understanding. Thus, in this simplified framework <u>Epistemology</u> can be seen as the 'mechanism' that links a particular <u>Ontology</u>

to a context-dependent Methodology, by which term we mean Praxis. As we will discuss below, the choice of epistemology is partly dependent on the ontology. Further, both epistemology and methodology have a chance to influence ontology through the medium of lived experience, which is shown in the figure as Empirical Feedback.

We should differentiate between the objectives of the digital ecosystems research initiative and the objectives of the series of deliverables that culminates with this report. Whereas the former aims to achieve sustainable socio-economic development catalysed by ICTs, as stated above, the latter aims to create a level of consensus across a growing, diverse, and increasingly global research community about the principles and methodologies that (1) are most pertinent to this research; (2) characterise the digital ecosystems communities of practice and of research; and (3) are most effective at facilitating the creation of new knowledge, new instantiations of digital ecosystems in new regions, and a continuous constructive interaction between theory, applications, and policy and between different disciplinary viewpoints. The series of deliverables D1.2, D12.1, and D12.10 (this one) present a theoretical framework that purports to satisfy these aims.

With the above in mind, we now describe the contents of the report. Chapter 2 discusses a fundamental ontology that we believe to be the bedrock of digital ecosystems research in all their manifestations, representations, and instantiations. As we mentioned above, we are taking somewhat higher-level constructs to act as fundamental building blocks of the theory. In Chapter 3 we address the challenge of reconciling different epistemological positions and vantage points as they inform the various scientific domains of digital ecosystems research. In Chapters 4 and 5 we outline how the frameworks described so far can be instantiated in the methodology of social science discourse informed by natural science and of computer science discourse informed by social science, respectively.

The third combination, i.e. the methodology through which the natural science discourse can be integrated with computer science, is still being pursued in the series of past and future deliverables D1.1 (Dini et al., 2008a), D1.2 (Dini et al., 2008b), D1.3, D1.4, and D1.5. Although the *mathematical* challenges posed by this research effort are enormous, the *philosophical* challenges are much simpler since from the very beginning of the digital ecosystems research initiative bio-computing was always meant to improve strictly functionalist parameters (such as adaptability and evolvability). This point has already been extensively discussed in previous work (Dini and Berdou, 2004; Dini, 2007a; Dini, 2007b; Dini et al., 2008a; Dini et al., 2008b; Dini et al., 2008c; Botto et al., 2008).

Chapter 6 will offer a synthetic view of how the many elements of associative autopoietic digital ecosystems can come together into an integrated theory, and Chapter 7 will conclude. The report also includes two appendixes, one as a broadly accessible short paper on digital ecosystems for dissemination purposes, and the other as an interdisciplinary glossary of terms.

2. An Ontological Framework for Digital Ecosystems

2.1 Introduction

Digital Ecosystems research has been funded by the European Commission under the auspices of its "Information Society Technology" programme (now renamed DG Information Society and Media). OPAALS research therefore needs to be broadly contextualised by literature that explores and theorises the information society, the new technologies that define it, the claims made regarding the impact of its rise upon the organisation of social life, and the possibilities it makes available for socio-economic development. At the end of the third year of the project we are in a position to offer a fundamental ontology for digital ecosystems research which underpins all our activities since the DBE project and which will continue to inform our vision for the foreseeable future. It is informative to use as a starting point a similar 'ontological statement' we made 2 years ago in drafting what was then the theoretical synthesis paper of the DBE project. In this manner we can provide a historical perspective on how our understanding of the theoretical foundations of this research has evolved since then:

> One of the most theoretically challenging hypotheses of digital ecosystems research is that biological metaphors and isomorphic models can bring significant advantages to the e-Business software development process, to the self-optimising and self-healing properties of distributed run-time environments and service-oriented architectures, and to ICT adoption in general through greater adaptability of the software to user needs. While the concept of business ecosystem is not new (Moore, 1996) and the application of biological concepts and models to software has inspired whole fields of research, such as Artificial Life, their application to software in an e-Business context is quite innovative. Similarly, whereas the complementary roles companies play in value chains is reminiscent of the interdependence between species in biological ecosystems, using the ecosystem metaphor to conceptualise all the business, economic, and social relationships between all the private and public sector players and the academic/research institutions in a whole region is rather more ambitious. Less contentious, but still far from clear, is the role of Open Source (and more generally of a "Commons") in lowering the barrier of ICT adoption for small and medium-sized enterprises (SMEs), the role all these factors play in catalysing sustainable socio-economic development, and what regional policies can be derived from the research and engagement experience with SMEs. Further, the language-based and collaborative processes through which social networks of SMEs can influence their own sustainability in regional economies are not well understood, but ICTs are widely believed to offer the potential to amplify this social constructivist dynamic. (Dini, 2007a)

In the above we recognise the importance of biological metaphors and models, and the ecosystem concept in particular, to improve the functional properties of the software. However, the same metaphor is also important for conceptualising economic interdependence. Finally, where the exchange economy meets the gift economy we see opportunities for a sociological perspective to inform the technical and economic dimensions through Open Source, collaborative dynamics, and language-based social constructivist processes. Where these are fundamentally important concepts for Digital Ecosystems (DE) research, it is not clear to what extent we can consider them as purely ontological. In this chapter we propose a set of concepts that can be considered in some sense more fundamental than the above, and whose ontological character can be understood more clearly in the context of Figure 1.1 and Chapter 3 of this report. We begin with a discussion of different definitions of 'digital ecosystem', for the sake of clarity and to highlight the importance of reflexivity in communications.

2.2 Definitions of Digital Ecosystems[1]

Boley and Chang (Boley and Chang, 2007) proposed a definition of a digital ecosystem based on an analogy with their own definition of ecosystem in the purely biological sense. In their view, a digital ecosystem is

[1] Some of the material in this sub-section draws upon the position paper by Krause et al. (2009) published in the *IEEE International Conference on Digital Ecosystems and Technologies* (DEST'09) where it won the best paper award.

> an open, loosely coupled, domain clustered, demand-driven, self-organising agent environment, where each agent of each species is proactive and responsive regarding its own benefit/profit (…) but is also responsible to its system.

A key feature of this is that agents join freely and of their own volition. This is in contrast to a tightly coupled organisation in which the agents have pre-defined roles. The focus is very much on the autonomy of individual agents and, hence, the global properties and institutions of such an ecosystem emerge (primarily) through self-organisation. This is a radical and potentially disruptive concept. However, we will argue later in Chapter 5 that current digital infrastructures constrain the emergence of properties and institutions and, instead, impose them from outside the ecosystem. To this end, we would like to work from a definition of an ecosystem that is at a higher level of abstraction. We take as our starting point the Arthur Tansley's 1935 definition of an ecosystem as

> an interactive system established between living creatures and the environment in which they live. (Tansley, 1935)

With regard to a digital ecosystem, we want to hold back any discussion around 'living' for the moment, and so work with the following:

> A digital ecosystem is an interactive system established between a set of active agents and an environment within which they engage in common activities.

Note that, consistent with this definition, it is possible for a given agent to interact in multiple digital ecosystems. "Agents" include (but might not be limited to) providers of software services, information sources, and human agents. The environment is a combination of a socio-economic context and a digital infrastructure. We will argue that the nature of the latter, the digital infrastructure, can impact (undesirably at present) on the properties that emerge in the ecosystem. Our view is that the concept of *species*, even in natural ecosystems, has some problems. Nevertheless, it is difficult to engage in any dialogue on ecosystems without some reference to species, a concept that can be useful of course. Boley and Chang referred to species as "types of agents" (Boley and Chang, 2007). We concur with that, but it still leaves open the question of how we define a taxonomy for digital ecosystems? This question will be addressed more fully in Chapter 6. Here, we only mention that in commerce a business enterprise can be viewed as providing a set of services. Insofar as such an enterprise provides a higher level of organisation than an individual service, we might consider (business) enterprises as species within an ecosystem. This equating of enterprise with species will be particularly useful when we come to discuss response diversity in digital ecosystems in Chapter 5.

Table 2.1 highlights how the definition of a digital ecosystem depends to a significant extent on the discipline to which the person doing the defining belongs. This table extends the multifaceted definition of a digital ecosystem we provided two years ago (Dini, 2007a).

Table 2.1 An Associative Autopoietic Digital Ecosystem is…

Social Science	***Computer Science***	***Natural Science***
• A community of users • A shared set of languages and collaborative practices • A self-reinforcing set of regulatory norms and guidelines to foster trust • A set of knowledge and business services • An economically sustainable open-source service-oriented infrastructure • A governance framework	• Several categories of users • A set of formal languages • A distributed security, identity, accountability and trust infrastructure • A service-oriented architecture based on a distributed transaction coordination model • A service development environment • A distributed persistent storage layer • A dynamic P2P run-time environment	• A population of interacting agents • A distributed evolutionary environment • A dynamic, adaptive, learning, and scale-free network infrastructure • An operationally closed and self-organising set of interacting multifunctional automata
Attempt at convergent definition		
• An interactive system established between a set of active agents and an **open, evolutionary** environment within which they engage in common activities		

2.3 Ontological categories

Mansell and Steinmuller (2000: 453) argue that the term 'information society' "implies the goal of achieving ubiquitous and accessible information resources as a foundation for economic growth and development" as well as the extent to which "information is becoming a central feature of social and cultural life". Ultimately, the "information society vision" should be understood as informed by and part of the neoliberal world view that characterizes economic life in North America and Europe, and it is driven by those "using the technology in the search for profit and according to the values of global capitalism" (Mansell, 2009: 7). A recognition of the ideological milieu in which technology research takes place is fundamental to the mapping out of its ontological categories. Castells (2000: 502) argues that the rise of "network society" has led to a "dramatic reorganisation of power relationships" and that "exclusion from these networks is one of the most damaging forms of exclusion in our economy and culture " (Castells, 2003: 3). Mansell (2002: 252) similarly argues that it is imperative that researchers focus on "social and technical interactions that structure, enable or constrain possibilities for human action in a world where digital technology is becoming more pervasive" and the need for "new understandings of the power relationships between social actors and new parameters for social inclusion and exclusion" (Mansell, 2002: 253). It is thus clear that questions of **power** are central, from the social sciences perspective, to research that takes place within the field of information society technology.

Furthermore, Mansell and Wehn (1998) explore in great detail the various complexities, challenges and opportunities posed by the evolution of "knowledge societies", highlighting the centrality of questions of **knowledge** within research addressing information systems and ICT development. Mansell (2008) opens her recent paper that critically reviews the "life and times of the information society" by citing David and Foray (2003: 20) who claim:

> Knowledge has been at the heart of economic growth and the gradual rise in levels of social well-being since time immemorial. The ability to invent and innovate, that is, to create new knowledge and new ideas that are then embodied in products, processes and organisations, has always served to fuel development.

This perspective that knowledge is merely a "productivity strategy to stimulate growth" (Mansell, 2008: 2) is shared by many commentators on ICTs, particularly those in the discipline of economics, yet has been problematised by social scientists who have researched the complexities of the effects of the rise of ICTs on social life and interaction. Mansell (2008: 3) points out that these assumptions are problematic and argues that despite criticisms of normative "mantras" of the Information Society, policy-makers remain unconvinced and that it is problematic to suggest that an increase in the availability of knowledge will automatically serve to drive development. We can thus see that there is a complex relationship between questions of knowledge and power in the context of information society technology research. Underlying and interlinking both of these issues and implied in phrases such as "social inclusion and exclusion" are questions of **democratic process** and governance – how inclusion or exclusion are enacted in policy, process, and decision-making. This is fundamentally related to the individualist/collectivist tension highlighted briefly in the discussion of the epistemological framework in Chapter 3 of this deliverable.

Implicit in questions of power allocation and distribution are the allocation, distribution, and creation of wealth, irrespective of the socio-economic criteria one chooses to rely upon to define this concept. However, the *dynamical character* of economic interactions is not fully accounted for by the three ontological categories introduced so far, so that we must add a fourth one, **non-linearity**. In truth, we could have chosen 'interaction', but such a choice is not sufficiently discriminating since one could arguably say that "everything is interaction". The conceptualisation and formalisation of non-linear interaction is rooted in the natural and physical sciences and mathematics, which therefore play a role for digital ecosystems research as fundamental as social science and computer science. Interestingly, non-linearity is as important to biological processes as it is to economic ones, as we will discuss further in this report, thereby demonstrating its 'foundational' character.

It is tempting to regard evolution as a fifth fundamental concept of digital ecosystems. However, not only are evolutionary thinking and evolutionary algorithms found in many other contexts but, more importantly, evolution could be regarded as the quintessential order construction process, through which

all of biology emerged. Thus, as an incremental memory-based process evolution seems to belong better as an epistemological category than to an ontological one, and this is how we will treat it in our theory.

Therefore, taking its cue from these core issues which are highlighted in leading scholarship on information society technology, this chapter explores a meta-theoretical view on four core ontological concerns related to Digital Ecosystems research: knowledge, power, democratic processes, and non-linearity. It will situate them as the four core ontological principles that underpin digital ecosystems research, and relate them to the social science research areas discussed in D12.1 and to our current thinking on the applicability of non-linear mathematics to biology and economics. Underlying the entire discussion in this chapter is an acknowledgement that technology does not exist in a vacuum, and that it is not value-free. New technologies, such as digital ecosystems, exist within local, regional and global social conditions, and are designed in order to advance those conditions. As will be done in Chapter 3, it is thus imperative to be able to clearly articulate, as part of a theoretical framework, the fundamental epistemological principles that underlie the research, based on the empirical, social and theoretical insights that have accumulated within the OPAALS research community over the first three years of the project. This in turn can allow for a clearer understanding of the sociological and socio-technical issues that could theoretically frame future work in this research area.

The discussion that follows explores knowledge, democratic processes, power, and non-linearity in the context of the OPAALS experience of digital ecosystems, but we believe it goes beyond this in terms of showing that the concepts have weight and importance in broader terms too. In other words, we propose that any future research that addresses the establishment of digital ecosystems, which needs always take place within a specific local, regional or national social context, should consider theoretical questions of knowledge, democratic process, power, and non-linearity as important parts of the model.

2.4 Knowledge

Underlying the complexities of research in the field of information technology and society is a more fundamental question, related to how we know knowledge itself; in other words, how we theorise knowledge to be relevant to digital ecosystems. If the intended outcome of DE technology is development (through the enablement of human actors), it is necessary to first theorise knowledge, and how it can be constructed and shared in research communities such as OPAALS. As the DEAL case study in D12.1 illustrated, knowledge is the *currency* in which digital ecosystems trade. Whether it is a digital ecosystem that functions as a self-generating communications portal for a community of practice, such as DEAL, or a scientific research community exploring the establishment of DEs themselves, such as OPAALS, it is clear that how we theorise and understand knowledge must be central to a theoretical framework for DEs. This is so both in relation to our scientific research activities as well as to the impact that this research can have on the socio-economic environment within which we, and SMEs, operate.

Knowledge can be considered central to OPAALS specifically (and to DEs in general) in two broad ways. The **first** is from the perspective of an inter- and multi-disciplinary research community, which sees the creation and sharing of, and open access to, knowledge as a fundamental motivation for its existence and continued work. In this sense, knowledge is the capital that is produced by the research community, and that is contributed to open, global knowledge flows. These concern digital ecosystems themselves as a research object, as well as the various flavours of social science, computer science and natural science knowledge relevant thereto. The latter is from the perspective of the sustainable community of researchers and of external stakeholders that will use digital ecosystems, which represents a **second** tier of knowledge about digital ecosystems and of its relevance to the day-to-day business activities of SMEs and their social (political, economic) contexts. Digital ecosystems researchers are part of the “knowledge society” that incorporates a great number of diverse actors: “generating knowledge is no longer exclusive to independent scientific institutions such as universities” (Anderson, 2003: x). Through a reflexive theorisation of knowledge, and its role in facilitating the establishment of DEs, it may become possible to critically reflect on how that knowledge can contribute to social development, rather than uncritically

assume that it does. One helpful way of theorising knowledge is through the concept of discourse, for which we are indebted to Michel Foucault.

2.4.1 Discourse

Foucault's perspectives on knowledge are expounded in various works, but particularly in *The Archaeology of Knowledge* (1969) and *The Order of Things* (1970). In the former book, Foucault outlines archaeology as an historical method of discourse analysis aimed at revealing the complex origins of scientific knowledge. Archaeology proceeds in the opposite direction to traditional historical research; "it seeks rather to untie all those knots that historians have patiently tied; it increases differences, blurs the lines of communication, and tries to make it more difficult to pass from one thing to another..." (Foucault, 1969: 187). By seeking out moments of rupture, divergence and non-linearity present within a discourse, Foucault intends his archaeological method to "explore the discursive practice/knowledge (*savoir)*/ science axis" rather than the "consciousness / knowledge (*connaissance*)/science axis"[2] (Foucault, 1969: 201-2). The latter book builds upon the former, and puts into practice the method by operationalising an "archaeology" of the emergence of scientific discourse, particularly that of natural history. These long and very complex works cannot be adequately summarised in all of their detail in this deliverable; instead it is pertinent to highlight the fundamental observations about knowledge as discourse that are relevant to digital ecosystems research. The first is that,

> According to Foucault … knowledge is embedded in the activities, social relations and expertise of specific communities, whether these are scientific, political, geographic or virtual. On this view, knowing is inseparable from action and environment, and is also inseparable from issues of access and empowerment (Carlile & Jordan, 2005: 23).

'Knowledge as practice' highlights the centrality of individual actors in the knowledge creation and management process. The impact of political, social, cultural and disciplinary pressures and perspectives will certainly shape knowledge as it emerges and evolves through discourse. Foucault treats discourses not as "a group of signs (signifying elements referring to contents or representations) but as *practises that systematically form the objects of which they speak*. Of course, discourses are composed of signs; but what they do is more than use these signs to designate things" (Foucault, 1969: 54 – emphasis added). In other words, discourse is a specific language about a specialised domain that is enacted through the practice of speaking about that specialised domain. In this sense, discourse can be conceptualised as something that self-forms, or evolves over time, and which takes shape in language. Foucault reiterates this position at several places throughout the *Archaeology of Knowledge*: "...discourse... [is] a practice, that establishes... a system of relations that is not 'really' given or constituted *a priori*..." (Foucault, 1969: 59) and, "Discourse, at least as analysed by archaeology …is a practice that has its own forms of sequence and succession" (Foucault, 1969: 187).

Recall that discourse in the sense in which we are using it here is specialised scientific language that is created by experts in that discipline in the process of speaking about, and therefore forming, that expert knowledge. In *The Order of Things* (1970), Foucault undertakes an historical analysis of scientific discourse, and argues that it should not be subject to "a theory of the knowing subject, but rather to a theory of discursive practice" (Foucault, 1970: xv). Working through the archives of scientific discourse from the 16th century onwards, Foucault highlights the close connection between natural language and natural science, arguing that the study of the latter sprung from the study of the former. The taxonomical drive of scientists of the late 16th and early 17th centuries (as illustrated by the classificatory project of the encyclopaedia, which aimed to catalogue explanations and descriptions of everything, arbitrarily arranged in alphabetical order) evolved into the project of classic empiricism, which Foucault summarises as the urge to "represent" knowledge as data. These various practices (and more, which we do not have the space to discuss here) evolve into complex systems geared towards the representation of knowledge that Foucault summarises as "discourse". By focussing on the discourse of natural history, Foucault reveals the

[2] "*Connaissance* refers here to a particular corpus of knowledge, a particular discipline – biology or economics for example. S*avoir*, which is usually defined as knowledge in general, the totality of *connaissances*, is used by Foucault in an underlying, rather than an overall way" (Foucault, 1969: 16, translator's footnote).

order of things or, to be more precise, the way in which the order of things was put into language through the scientific observation of the natural world:

> Things and words are very strictly interwoven: nature is posited only through the grid of denominations, and – though without such names it would remain mute and invisible – it glimmers far off beyond them, continuously present on the far side of this grid, which nevertheless presents it to our knowledge and renders it visible only when wholly spanned by knowledge (Foucault, 1970: 174-5).

The interweaving of words and things, and words about things (in Foucault's example, the things that occur in the natural world), is seen as the fundamental core of knowledge as a self-generated, active, dynamic and constantly evolving phenomenon. Nature is made knowable through the discourse of natural history, itself enacted through the practices of observing and describing (in words) nature. That knowledge is a discourse (a set of practices) means that knowledge is enacted through language. This discursive view on knowledge highlights and reaffirms OPAALS commitment to *language* as an applied area of social science research.

2.4.2 Language and knowledge

Foucault makes explicit the connection between knowledge and language, claiming that they "are rigorously interwoven" and that they "share, in representation, the same origin and the same functional principle; they support one another, complement one another, and criticise one another incessantly" (Foucault 1970: 95). In seeking to use language as the tool and practice with which new knowledges about digital ecosystems are constructed, it is correct to centre it within the theoretical framework and philosophy of OPAALS. This is acknowledged and explored in the work of WP6 in a very practical and applied fashion: "it is language that constructs our communities and by means of which we can depict, share, and manage knowledge" (D6.3: p. 52). This much is already evident and clear to the OPAALS partners, and it is not necessary to repeat in this deliverable the work on language that has already been done in others. It is, however, necessary to highlight that it is exactly because knowledge is inextricably related to language that the latter is centred in our research, and that a theorisation of knowledge as discourse (i.e., practice), following Foucault, should be a fundamental element of any theoretical foundation for digital ecosystems.

Rempel (1996: 21) has compared Foucault's treatment of discourse with Luhmann's formulation of language as a subsystem of social communication (he makes a similar comparison of the two theorists views on the the question of power, which is elaborated in further detail in Section 2.5.1). Rempel points out that a key difference between them is notable in how "Luhmann analyses the truth-seeking language of 'science', while Foucault analyses the distinct 'regimes of practice' that produce 'truth' in each of a multiplicity of scientific sub-disciplines" (ibid.). These differences are not negligible, the list can certainly be extended and it is neither advisable nor possible to reconcile the two theoretical approaches. However, the fact that both Luhmann and Foucault theorise the relationship between knowledge and language is notable. Language and knowledge are indeed knitted together, at both the theoretical and applied levels. In terms of the latter, the implications of the relationship between language and knowledge for the study and establishment of digital ecosystems is that, because language and knowledge are co-constitutive, knowledge as an ontological category is inaccessible and redundant without language. Thus, language can be considered a tool, not only for communication, but also for the construction of knowledge.

2.4.3 Language and technology[3]

In digital ecosystems research language is seen as the driver and enabler of the construction of social and economic spaces, ICT as a catalyst of this process, and our role to understand how the constructive power of language can be harnessed by ICTs to realise sustainable socio-economic growth at the regional scale. The importance of language as medium of power relationships (with the attendant challenges in the management of scarce resources and in the governance of democratic institutions) is one of the fundamental assumptions of social constructivism. The introduction of technology into the mix, however, adds another level of complexity.

[3] This sub-section is based on Dini (2007a).

As discussed in Feenberg (2005), in Heidegger's early writings "Aristotle's conception of being in general is derived from the Greek practice of technical making, from τηχνέ". τηχνέ realises the inherent potentialities of things rather than violating them as does modern technology. Compatibly with this position, according to Marcuse the task of a post-Heideggerian philosophy is to conceive a technology based on respect for nature and incorporating life-affirming values in its very structure, the machines themselves. This utopian demand can be understood as "an implicit recovery of Aristotle's idea of τηχνέ in a modern context, freed from the limitations of ancient Greek thought and available as a basis for a reconstructed modernity". Making things (i.e. engineering) can then be recovered as a life-affirming, deeply human activity, as long as we are not blinded by the myth of the neutrality of technology in an objective world. Feenberg's critical theory of technology shows how technology embodies our cultural values and is in fact an extension of our human languages that necessarily generalises the concept of symbol. The language-technology continuum then contributes to the construction of our understanding of reality and in particular of our social reality.

In this panorama of ***technology recast as an extension of human cultures and languages*** ICTs play a unique role because, not only do they share with other kinds of technology this cultural and expressive valence, they *mediate* the very communications that construct the social and cultural systems that created them. It is not clear what the effect of this tight feedback loop might be, but it is pretty clear that it is likely to be a strong one, and perhaps not so easy to control. When looked at through a social science 'lens', therefore, the hybrid role of computer science is perhaps best captured by Winograd and Flores' view of computers as communication media (Winograd and Flores, 1987). Because communications, in turn, carry commitments (Austin, 1962; Searle, 1979; Flores and Spinosa, 1998), it becomes easier to accept that ICT has the potential to become a catalyst of social constructivist processes.

The thread that begins with language, therefore, can be seen to account for software *design* and software *use*, but not software *synthesis* in the biologically-inspired sense being pursued in WP1.[4] Software use or more generally *communications* do seem to provide an overlap between these very different perspectives. If we examine the finer-grained structure of language we notice that it can be further divided into a more mechanical and objective syntax, and more intersubjective and context-dependent semantics and pragmatics. The levels are in fact many more than two or three (as maintained in intertextual analysis, cultural studies, literary theory, etc). Communications, therefore, appear to span the whole spectrum of media, from machines to poetry, which can be seen as a many-layered 'media stack'. Because at one end of this stack language can be understood as a medium of social construction, while at the other end technology is influenced by cultural values, the media stack is not linear but loops back on itself in a self-reinforcing dynamic. Figure 2.1 gives an Escher-like graphical rendition of the feedback loops generated by the interaction of ICTs and media content, which could be described through the metaphor of autopoiesis.

2.5 Power

Exploring theories of knowledge, as we have done thus far, in turn insists upon a clear conceptualisation of power. In the social sciences, power is one of those baseline concepts that influence almost every other area of social research and analysis (not unlike the role of maths in the natural and physical sciences). Conceptualising power is important in the context of digital ecosystems so as to be able to answer questions such as, but not limited to, who holds the power in digital ecosystems research? How is power shared amongst the members of the community? How can power be extended and shared through digital ecosystems research? These types of questions are fundamental to the motivating force of OPAALS's digital ecosystems research. By exploring theoretical approaches to systemic power, the foundations of the possibilities for empowerment – where this means the ability of social actors to participate in the power relations that surround them and enable or constrain their actions – can be explored and perhaps contribute, on an ontological level, to the ultimate aim of DE research: the empowerment of SMEs and a contribution to socio-economic development.

[4] Socio-economic inputs to the products of self-organising bio-computing processes are provided through the evolutionary framework, still under development in WP1 because of its coupling to gene expression computing.

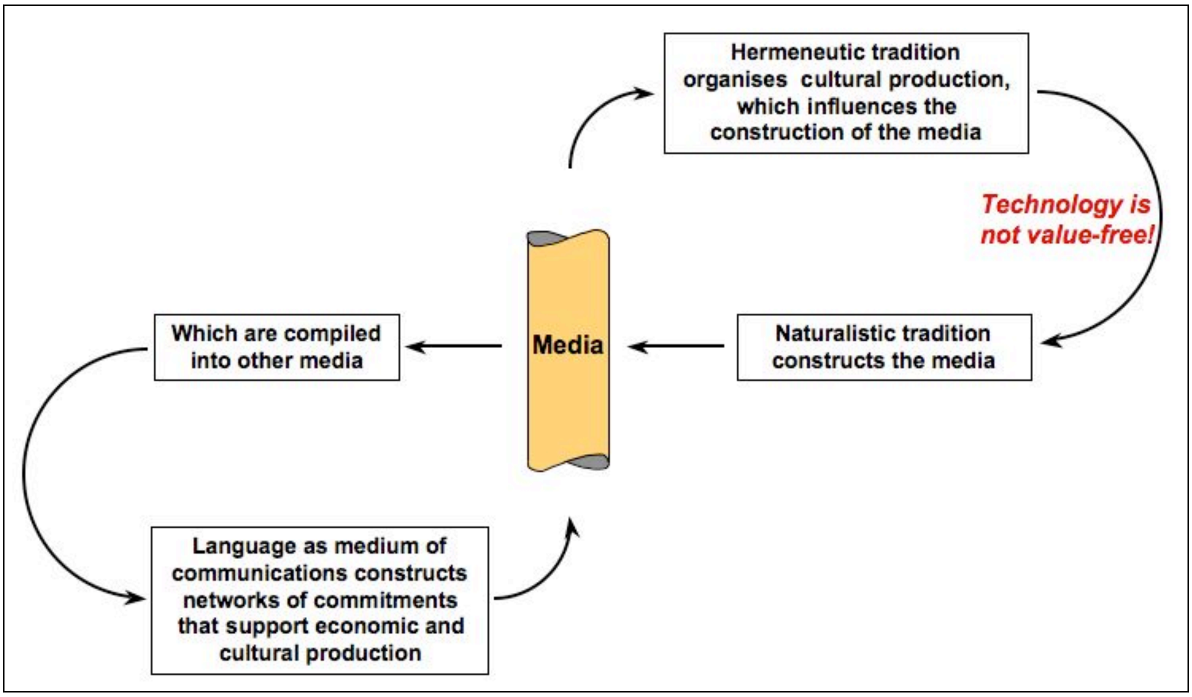

Figure 2.1: Autopoiesis of media

2.5.1 Two views on systemic power

An exploration of the notion of power is inextricably linked to governance through democratic process, as well as knowledge through language. This sub-section aims to juxtapose two systemic views on power: that of Luhmann and that of Foucault. The aim of this is not to suggest that the theorists can be reconciled, as they undoubtedly cannot, but to highlight alternative conceptualisations of power applicable to the internal dynamics of socio-technical systems, as well as their interactions with the rest of society. The aim of this discussion is merely to highlight at an ontological level how different conceptualisations of power can feed into the theorisation of digital ecosystems, and is fundamental to any sociological framing of this area of interdisciplinary research.

Debates surrounding Luhmann's use of the concept of autopoiesis in his theories of social systems were addressed in detail in D12.1, and are explored again in Chapter 4 of this deliverable. Although it may result that Luhmann's work is ultimately not considered by the OPAALS community the most appropriate for the theorisation of digital ecosystems, the fact that he is one of the most recognisable and leading scholars to have worked with the concept of "autopoiesis" in social systems theory, and the centrality of this concept to the natural and computer science elements of the research being done, requires an exploration and assessment of his work from the social science perspective. For the purposes of this discussion, at the ontological level of systemic power, it is necessary to consider only how Luhmann's version of social systems theory sees power as the medium of communication unique to the political subsystem (Borch, 2005: 155), where "it comprises the basis of authority to use the generalised medium of power to execute collectively-binding decisions" (Rempel, 1996: 64). Because each subsystem is autopoietically closed off from the others and operates independently, each system's binary code generates, and applies to, only its own operations: "Through his orientation to autopoiesis, Luhmann is *not* receptive to the possibility that multiple power/knowledge forms combine within a given social domain" (Rempel, 1996: 83). Luhmann conceptualises power purely in political and adversarial forms, whereby opposing parties struggle to become the "government" and the non-successful participant becomes the opposition (ibid.). Other components of society, such as the legal, scientific, media, or religious subsystems have their own binary codes that determine their internal operations. This autopoietic/systemic view on power is rigid, and many social scientists would agree that it does not take adequate account of the intricate complexities and interlinking phenomena of everyday life. Luhmann's model would seem to suggest that power is only relevant to digital ecosystems inasmuch as they are regulated by the political systems that govern societies, and some may argue that this view of power as an autopoietic property of political systems does not in fact capture the complexity and fluidity of the power relations that

characterise a digital ecosystem like OPAALS. Our community's clearly elucidated social science research priorities make it clear that (self-) governance is a central focus of our research, which seeks to provide a model for best practice in the field and to emphasise participation and transparency (rather than autocracy or a two-party model). Furthermore, our emphasis on micro-empowerment (of SMEs and individual agents in regions) betrays a keen awareness of the fact that power is not confined to political processes but diffused throughout many other aspects of social life, including the technological, the social, the economic and the cultural. It is clear, therefore, that Luhmann's particular formulation of power in his broad-ranging systems theory does not provide us with the conceptual tools that are necessary to the theorisation of a concept so fundamental to our aims and operations, and is therefore insufficient for the theorisation of digital ecosystems.

A more appropriate model of power can be located in the work of Foucault, whose useful and applicable insights into the operations of power in various aspects of social life have had huge influence on wide-ranging social research and theorisation. Ironically, Foucault does not theorise power head-on, but instead through a variety of historical analyses of the micro-operations of power in various institutions and practices of social life, for example prisons (1979), insane asylums (1967), and discourses about sexuality (1981, 1985, 1986). Although Foucault did not study emerging technologies directly, his descriptions of the abstract operations of power could nevertheless be considered transferable to the study of an emerging technology and community such as a digital ecosystem.

The most fundamental, and influential, contribution to theorising power that Foucault makes is that it is not top-down, in the model of ancient monarchs who imposed their will upon citizens, nor a static rigid system somehow separate from other aspects of social and technical life, as per Luhmann. Foucault "is critical of the so-called discourse of sovereignty where power is understood negatively, reflecting a basically pre-modern social structure, and which he believes to be inadequate for contemporary power analysis" (Borch, 2005: 156). Instead of seeing power as a vertical, top-down, repressive system, Foucault sees it as a horizontal and ever-shifting set of relations. As Deleuze (2006: 59) summarises, "power is a relation between forces, or rather every relation between forces is a 'power relation'". This set of relations is not a form, in the way in which we understand political parties or the state as institutions, neither is it, Deleuze continues, something that lies between two forms (such as the state and the citizen, or in other words, the collective and the individual). Furthermore, in the Foucualdian view, power is plural and always a set of relations (ibid.). In other words, according to Foucault, power is present in every aspect of social life, and is enacted through the relationships and activities of all those who participate in social life. Although the very notion of 'empowerment' implies that some are excluded from power relations, it should be emphasised that power takes a variety of forms, and should not only be conceptualised as political or economic, for example (where clear situations of exclusion can be noted). This is exactly the important insight that is of great relevance to digital ecosystems, and which allows a theorisation thereof that goes further than governance and socio-economics, without necessarily abandoning such fundamental concerns either.

Foucault's much-cited example of how power can insinuate itself even into the behaviour of individuals is the famous 18th century prison designed by Jeremy Bentham: the Panopticon. The building was designed in order to allow a simple system of surveillance: all its occupants were visible to a central control tower and to one another. This allowed for the institutionalisation, not of a person in control and enforcing submission to his will, but of "an inspecting gaze, a gaze which each individual under its weight will end by interiorising to the point that he is his own overseer, each individual thus exercising this surveillance over, and against, himself" (Foucault, 1980: 155). This is an extreme example of how power is redistributed into a set of relations (in this example, of observation and surveillance) and interiorised into the behaviour of each individual's actions, rather than operating in the hands of one person or institution and being imposed on others. In the context of digital ecosystems, it is extremely helpful to conceptualise power as a distributed set of relations, which in some ways mirrors and is constructed by a distributed architecture and collaborative governance, and to note that in every exchange and interaction between members of the community power has influence and is in turned constructed, exchanged, and shared in a variety of ways, at a variety of levels.

Following on from these two brief summaries of Luhmann and Foucault's views on system power, respectively, we can summarise the differences between Luhmann and Foucault's conceptions of power with the help of Rempel (1996: 22), who argues:

- While Luhmann sees power as a relatively value-or coercion-neutral communications medium, Foucault sees power as the relations of force that produce constraint, control or an imposed social construction of some kind.
- While Luhmann limits power's proper and normal location to the political subsystem and sees it as the generalised medium of communication that enables legitimate political actors to select some collectively binding decisions over others, and then to act constructively and authoritatively based on those selections, Foucault sees power relations as pervasive in all social domains.

Despite their clear and pervasive differences, it has been argued that the two influential theorists share similar "epistemological–analytical perspectives – on difference rather than identity, on second-order observation rather than positivism, on communication rather than subjects" (Borch, 2005: 155). These similarities suggest that it may be productive to confront their approaches on power so as to extend and deepen an analytics of power from a systemic viewpoint – as Borch (2005) attempts. He argues that Luhmann's conceptualisation of power contains two contradictory elements: the first is the evolutionary viewpoint, which maintains that power as the communication medium of the political system is "a byproduct of societal evolution or, more accurately, as an effective means of dealing with increasing complexity"; the second is Luhmann's argument regarding the isolated and autopoietic functional differentiation of that medium of communication (Borch 2005: 164). He concludes,

> a sophisticated analytics of power, combining a complex theory of society with an evolutionary dimension, would profit from using Luhmann's functional definition of power as analytical starting-point, examining how action in the concrete is regulated through action, that is, studying what forms the exercise of power takes *in actu*. Such an approach would be open to Foucault's argument that in modern society we may observe simultaneous workings of different forms of power (Borch 2005: 164).

If we accept Luhmann's notion that power is functional (as a medium of communication), it becomes clear that it needs to be theorised in broader operational terms, as relevant to almost every layer of social life and experience, and thus implicitly also between individuals and collectives. This includes the technological (how technology is developed and used), the political (how communities form, associate and self-govern) and the social and cultural (how individuals relate to themselves and others within the broader contexts of their environments and responsibilities). Without seeking to conflate or marry the two theorists, this argument simply allows for the two approaches to coexist, with Luhmann's functionality as a starting point, and Foucault's productive and discursive view on power allowing for a more nuanced, flexible and subtle understanding of its operations.

Power, thus, cannot simply be apportioned off as something to do only with the functioning of politics, but must be theorised as a central element to the micro-processes of digital ecosystems research and establishment. Rempel (1996: 25), following Foucault, proposes the application of "systems-theoretic concepts on three levels: the *social domain*, the *institution*, and the *site.* …it remains important not to confine attention *just* to the more micro level site but to seek out power/knowledge at the local, regional, institutional *and* macro levels". In the context of digital ecosystem research, the social domain can be understood as the broader socio-economic context in which the technology is being developed (the "information society" largely depicted through the neoliberal ideologies that partly animate it), the institution can be considered the peer-to-peer architecture and collaborative governance processes of each digital ecosystem, and the sites can be noted as multiple and various: the individually contextualised loci of digital ecosystems users and community members.

The discussion thus far has elaborated upon the operations of power from the perspectives of Luhmann and Foucault. Next, it is necessary to turn to an exploration of the relationship between power and knowledge.

2.5.2 Knowledge and power

As discussed in Section 2.2, we can conceptualise knowledge as the dynamic and evolving outcome of practices of discourse. Likewise we have seen that power is present in the practices and operations of everyday life. The relationship between power and knowledge, therefore, hinges on the concepts of practice and discourse. As Deleuze summarises,

> The sciences of man are inseparable from the power relations which make them possible, and provoke forms of knowledge (*savoirs*) which can more or less cross an epistemological threshold or create a practical knowledge (*connaissance*)… (Deleuze, 2006: 62).

Furthermore, Foucault explains that

> …power produces knowledge (and not simply by encouraging it because it serves power or by applying it because it is useful); …power and knowledge directly imply one another; … there is no power relation without the correlative constitution of a field of knowledge, nor any knowledge that does not presuppose and constitute at the same time power relations (Foucault, 1979: 27).

Power therefore can facilitate or help to create new discourses of knowledge (this certainly applies to the OPAALS project, which has been funded to research Digital Ecosystems, and thereby contribute to an emerging body of interdisciplinary knowledge). If knowledge is closely linked to the performative actions of language and discourse, then it requires the kind of power relations that enable and facilitate those actions. Arguably, good research is best enabled by horizontal and transparent power relations, which allow a free flow of ideas and discourses in the project of knowledge creation. Furthermore, it is clear that it is possible for "knowledges [to] become powers" (Rempel, 1996: 20), in other words, for knowledge in the plural to empower individual actors and communities, as well as to have a lasting impact on policy, scholarly thought and future research. This indeed is the ultimate aim of any research undertaken by a Network of Excellence. Similarly, it is important for digital ecosystems researchers to reflexively acknowledge that they hold power through their knowledge – which once again highlights the importance of a commitment to democratic process. Mansell (2008: 13) argues, "policy makers need to be provided with research findings that help them to depart from the mainstream perspectives that envisage linear, technology-driven approaches to information societies". In this way, it is clear that the types of knowledge discursively created through DE research are multifaceted, and may not only feed into political power structures but challenge and complicate them.

2.6 Democratic processes

In various OPAALS deliverables that have been produced in first two years of the project, as well as in the debates and discussions that have characterised mediated and face-to-face meetings between members of the consortium, a recurring concept has been that of *theoretical multidimensionality*. This is simply a way of saying that there exist within the OPAALS consortium a wide variety of theoretical, philosophical, epistemological and methodological beliefs and positions. For example, with regards to the governance of digital ecosystems, D12.2 put forward a "taxonomic classification of key terms and relevant research that can support the ongoing collation and consolidation of governance research on digital ecosystems" which emphasised the constantly shifting, multidimensional nature of both theory of and empirical research into governance issues. Similarly, in D6.3 a "metaphorological toolkit" is developed which emphasises the "infinite variety and creativity that constitutes natural language" and explores an applied approach of various linguistic methods within metaphorology to the emergence of digital ecosystems through natural and computational language. Milestone M10.7 reviews a selection of theoretical positions that could add value to an epistemological foundation for interdisciplinary research. Deliverable D12.1 offers a collection of interdisciplinary and theoretical viewpoints on Digital Ecosystems. As well as within individual deliverables, there exists a wide range of theoretical approaches across all deliverables, which is to be expected considering the interdisciplinary nature of the research project.

There is no reason to believe that OPAALS's variegated profile is particularly unique; in many respects it mirrors the diversity present in society at large. It is reasonable to imagine that all digital ecosystems

formed as communities of practice (for whatever purpose: enterprise and trade, agricultural development, or research) will experience a similar depth and breadth of difference in membership and imagination. How that difference is dealt with from governance and communications perspectives is a crucial element to any digital ecosystem's survival. Democratic process is helpful in terms of framing the challenges that arise from diversity, which can be understood to operate on various levels: cultural, social, linguistic, theoretical, philosophical, epistemological, and so on. Furthermore, a discussion of some of the underlying roots of the type of democratic process common to the West can operate as a starting point for the applied research area of governance. The discussion here will address theoretical insight into the types of democratic principles prioritised by the OPAALS community, which underlie interdisciplinary research and are relevant to digital ecosystems more broadly. The discussion will be based largely on a discussion of the roots of democracy in Europe, and in this sense is inevitably partial and to some degree incomplete, considering the international profile of the OPAALS community and the possibility for DE research to be appropriated and applied in non-European contexts. Nevertheless, we believe that some core principles rooted in European notions of democracy are helpful for framing an ontological view on governance and the processes by which DE communities can form and self-govern.

2.6.1 Moral equality and citizenship

An important starting point for a community consisting of a diversity of viewpoints and theoretical positions is the fundamental assumption of "moral or natural equality – which should be seen as a presumption in favour of equal treatment" (Siedentop, 2000: 57). In other words, there can be no presumed hierarchy of value with regards to the participants involved in any form of exchange or communication. In western philosophy[5], the assumption of moral equality, what Siedentop (2000: 14) terms the "moral residue of Christianity in Europe", has its roots in the church and European versions of Christianity, where each individual is "equal before God". The important concept here is "equal", rather than "God". In other words, from the point of view of the evolution of a democratic consciousness of the citizenry at large, Christianity could be seen as an effective 'stratagem' to push an agenda of equality. In this sense, the religious dimension is entirely orthogonal to this discussion. According to Siedentop, the concept of universal equality gradually morphed into a liberal viewpoint that insists that everyone's moral value is equal and that all voices should be heard in democratic processes. Siedentop argues that this discourse has been integral to "the development of modern Europe" (Siedentop, 2000: 57). This deliverable is not the place to discuss in detail the various philosophical debates that characterise the concept of equality. Rather, we simply wish to point out how this idea of moral equality, so common and recognisable to the democratic discourses of societies in the west and beyond, can be considered relevant to the project of digital ecosystems in general. As already pointed out, digital ecosystems host a very wide variety of different viewpoints; it is imperative therefore that each of these viewpoints be accorded moral equality, not before some kind of divine gaze, but before the collective consciousness and shared identity of a digital ecosystem. It also means that individual actors within the DE (be they SMEs or individual researchers) will be compelled to behave as good citizens in the recognition of the value and importance of the theories and ideas of others.

In democratic theory, the concept of citizenship is core. It implies participation and a concern with the welfare of the community, something that can only be achieved through collective action on issues of common concern. Siedentop (2000: 62) distinguishes between two types of self-governance, one which is defined by the idea of citizenship and patriotism, rooted in the ancient city-state where citizens were self-sacrificing public defenders/warriors, the other which is defined by the idea of individual sovereignty and rights, rooted in the rise of civil society and the discourse of human rights. Each of these perspectives can be summarised as the individualist and the collectivist view on citizenship. The former model begins with the group; the latter with the individual, and the tensions between the two approaches to citizenship define

[5] We are aware that the discussion of the principles underlying democratic process in this section are Eurocentric in that they rely upon theorists (such as Siedentop and Mouffe) who have focussed upon democracy in Europe. This is not intended to exclude other non-western paradigms, such as Asian, Latin-American or African traditions of political thought. It is merely intended to highlight certain underlying principles that we argue are relevant to the process of establishing and governing digital ecosystems, which will indeed differ in changing cultural contexts. The Eurocentric approach noticeable here should not be taken as an exclusive feature of the theoretical framework for digital ecosystems; indeed, non-western contexts are also a part of the OPAALS research umbrella, as illustrated by the discussion of the DEAL case study in India in Chapter 4 of this deliverable.

many of the problems faced by modern democracy, especially in Europe. Although this deliverable does not have the scope to address this issue, it can assess how the idea of citizenship is applicable to the context of digital ecosystems. Once again, it is relevant in a meta-theoretical manner: if the ideas that populate and create digital ecosystems are considered citizens, as well as the individual actors, then it becomes clear that their participation (fulfilling the roles and duties required as citizens) in the community is based on an assumption of equal treatment and fundamental respect for difference and individuality.

What requires consideration next is the question of what to do with these differences of idea, opinion, theory, and philosophy. Can they be reconciled? Should they? How do digital ecosystems cope with the diversity of citizenship experienced, and the commitment to treating all ideas as equal?

2.6.2 Consensus Building

Once it has been established and accepted that difference exists within a social system or space (digital ecosystems, for the purposes of our discussion), it is crucial to next address how that difference can be dealt with within the framework of debate, deliberation and governance. Habermas's (1964) notion of the public sphere as a communicative space where rational, equal actors convene to discuss matters of common importance is a helpful, although somewhat idealised, model. In Habermas's public sphere, a shared commitment to democratic processes and a shared interest in matters of public concern converge into a process of deliberative communication where all participants aim to smooth out disagreements and reach consensus about the processes that will govern their community. This is a normative model, which is possible and desirable in the governance of a project such as OPAALS, but which will likely only evolve over a longer period of time. Despite the central importance of this theory of deliberative democracy in much social analysis and research, it is widely agreed that it is deficient in the sense in which it does not take into account the role of *difference* in society (see Benhabib 1995); Habermas assumes certain homogeneity to exist in the collection of rational debating actors. Yet we are aware that there exists great diversity of ideas in OPAALS, and a similar level of diversity can be reasonably assumed to exist in all digital ecosystems. The presence of this diversity in turn leads to the necessity for debate and deliberation amongst community members about the best ways forward for the entire community.

It is helpful, therefore, to consider the process of consensus building as a communicative process that involves the development of a complex and adaptive group identity. The processes involved in the establishment and development of group identity are articulated in detail in Deliverable D9.7. Here, it is simply helpful to point out that democratic processes enable agents to define a set of statements to which they subscribe, and that can enable collaboration between them. This does not mean that all conflict must be eliminated from democratic process, but rather, as Mouffe (2000) argues, that difference of opinion and idea should be recognised and legitimated. Conflict should not be repressed nor attempts be made to synthesise opposing viewpoints into a new, shiny whole that erases the differences as they stand; rather, they should be allowed to coexist in their difference, and even vibrantly, but respectfully, clash against one another. Mouffe argues, "a democratic society acknowledges the pluralism of values… and the unavoidable conflict that it entails" (Mouffe, 2000: 103).

Mouffe writes in the context of changing democracies in Western Europe, and her remarks are clearly focussed on the politics of democratic process. Her concerns are directly with political process in western democracies, and how the huge diversity of interest groups, cultural and religious interests and political standpoints can be theorised as central to democracy as a form of government. We are well aware that digital ecosystems are not democracies in the political sense. Despite this, there is a clear necessity for some kind of theoretical commitment to *democratic process* so as to ensure that the inevitable diversity of a DE community is respected and harnessed in a fruitful and positive way. There is metaphorical relevance and importance in which democratic process can inspire governance in digital ecosystems. Whilst striving to maintain a respect for complex diversity and interdisciplinary differences of opinion, it is nevertheless crucial to harness democratic processes to create mechanisms of creating deliberation on matters of common concern, and to reach consensus on important decisions that affect all members of the community, be it a funding contract amendment or choices between different technology options, and the uptake and adoption thereof. Whilst recognising the difficulties and potential clash of ideas that result

from democratic processes, it remains reasonable and proper to emphasise the importance of a concurrent, parallel commitment to deliberation, in which all members of a Digital Ecosystem will be able to reach a shared, smooth and even consensus on the matters that concern them (such as the technologies that will best suit their needs, or the most appropriate modes of communicating with one another). This latter, more Habermasian view, is theoretically at odds with Mouffe's views on the centrality and importance of conflict, and our aim here is not to conflate these two opposing theorists or flatten out their differences in opinion when it comes to democratic process, but to highlight how, in the context of digital ecosystems, conflict (be it theoretical, disciplinary or epistemological) is inevitable, and requires both an acknowledgement of the role of disagreement and debate, and of the importance of working towards consensus where possible. Where it is not, conflicting opinions, theories and views should be permitted to agree to disagree, and to coexist in a mutually respectful manner within the digital ecosystem community.

2.7 Non-linearity

In contrast to the preceding discussion on the other ontological categories, a discussion of non-linearity is necessarily mathematical in character. This provides an opportunity to pay tribute to 'the other half' of software technology, which is mathematical. In particular, at its most fundamental level computer science is dependent on the implementation by means of logic gates of mathematical functions operating on the 'binary numbers' 0 and 1. The finite set of integers formed by the two elements 0 and 1 is called $Z_2 = \{0,1\}$ and with the operations 'addition' and 'multiplication' it satisfies the properties of a mathematical 'field'. If instead of the addition and multiplication we append to Z_2 the three logic operations 'AND' , 'OR' and 'NOT', the resulting mathematical construct becomes a Boolean algebra. The field and the Boolean algebra over Z_2, together, are important to computer science because they are 'functionally complete'. This means that any mathematical function that maps an arbitrary number of inputs taken from Z_2 to an element of Z_2 can be expressed as a polynomial in Z_2 that uses the above operations. Because a Boolean algebra is isomorphic to propositional logic, any such polynomial can be expressed as a set of logic gates, which can then be implemented in hardware in various ways. Because a very large number[6] of abstract operations that are relevant to human beings can be cast in the form of such mathematical functions, so-called general-purpose computers can support a huge and growing number of human or human-relevant (i.e. control systems) activities and process.

The problem of transforming mathematical operations into other forms of expression that can represent natural or physical phenomena or human languages has given rise to the field of formal language theory, characterised for example by Chomsky's hierarchy of formal languages (1957), with the corresponding hierarchy of machines and the field of automata theory. Formal languages and their corresponding machines, culminating with the Turing Machine, are associated with different complexity classes. For ease of reference we reproduce here Chomsky's hierarchy, which we had discussed in Dini (2007a):

- (Type 0) Turing Machines (TMs) are the most general and recognise anything (although not necessarily in finite time)
- (Type 1) Bounded-tape Turing Machines are more complex than Type 2 and recognise context-sensitive languages
- (Type 2) Pushdown Automata (PDA) have a stack and recognise context-free languages
- (Type 3) Deterministic Finite Automata (DFA) recognise Regular Languages (simple commands like 'ls' in Unix to list directory files)

For any one of these levels we can transform a given set of instructions between different representations, a fact that has given rise to the large and growing number of software engineering languages. For example, Java falls somewhere between Type 1 and Type 2, and compilation to Byte code and subsequently to Assembly and Binary does not change its complexity class. The many software engineering languages have, further, been organised in different 'generations', each new generation being able to express human requirements in way that is steadily approaching natural language (i.e. the language

[6] We say "a very large number" rather than "all" because some operations are not regarded as computable in useful or finite time, or computable at all!

SBVR, or the Semantics of Business Vocabulary and Business Rules, that has been extensively studied in DBE and OPAALS).

Because formal languages in current use can be reduced to Boolean algebra expressions, in our opinion much of the 'mystery' and 'value' of today's software derives not from its mathematical foundations but from its coupling to social and natural language processes, to knowledge, and to different forms of cultural expression (multimedia, music, etc). In other words, from the 'values' that it embodies, as shown in Figure 2.1. Some of the challenging and interesting couplings of computer science to social science have already been addressed in Section 2.4.3 on language and technology, and will be explored in significantly greater depth in Chapter 5. We can confidently say that many of these couplings, our awareness of which has grown in the past 7 years and that we have formalised through particular architectural choices and criteria, can collectively *define* digital ecosystems from the point of view of social science, because no other socio-technical and economic system that has been developed so far satisfies them in the same way.

By contrast, the mathematical properties of software as we understand it today are not 'mysterious' in the sense that we understand how to reduce everything to propositional logic, Boolean algebra, and truth tables. Thus from the point of view of a theory of digital ecosystems, what we have said so far in this section about the mathematical foundations of computer science is not differentiating: everything we have said so far is common to all software systems, nothing about it is unique to digital ecosystems.

Our intention since 2002 has been to endow software with self-organising properties that transcend memory-based processes such as biological evolution and achieve the bewildering expressiveness, flexibility, and dynamic stability of cellular processes – i.e. of the 'computation' performed by the cell. Whereas from the physics point of view it was very clear that we needed to understand how non-linear systems are able to construct order dynamically, without a blueprint, we had no lever to address this problem within a computer science context. But this is now changing.

By following the most powerful and general epistemological ordering principle of quantitative science, symmetry, we gradually uncovered (mainly through published literature) a set of algebraic properties of bio-chemical systems discretisable as finite-state automata that we are currently trying to relate mathematically to the symmetries of the non-linear dynamical systems derived from the same bio-chemical systems. This work is being reported in D1.3, D1.4, and D1.5 (as well as in BIONETS deliverable D2.2.9) so we do not need to linger more on the details here, other than to mention a very interesting extension of the concept of functional completeness.

It has been known for many years that the concept of functional completeness can be generalised beyond fields and Boolean algebra. In other words, one can use more general algebraic structures to achieve equally functionally complete computational models. In particular, as discussed in D1.3, Horvath (2008) investigated whether a semigroup can have the functionally complete property expressible as more general 'polynomials' than propositional logic. He proved that the answer is Yes, as long as the semigroup is a finite simple non-abelian group. Because, even though they are somewhat special, there are infinitely many such groups, this means that we could build a 'more complex' computer science using more complicated fundamental structures. The subfield of category theory called universal coalgebra would then enable us to transform such algebraic structures into corresponding logics, a research topic that is being pursued within the BIONETS project.

To close this section, we chose non-linearity rather than symmetry as an ontological category for digital ecosystems because symmetry is ubiquitous, nothing about it identifies digital ecosystems uniquely.[7] By contrast non-linearity in computation is a concept that, although it has has been around for a long time (Kalman et al., 1969: 8), does not appear to have been purused in its own right. Thus we think it may have a chance to open the door to 'ecosystemic and autopoietic computing'. Rather than introducing yet another term (beyond Interaction Computing, Gene Expression Computing, Symbiotic Computing, etc), this term is meant to highlight the fact that without non-linear interactions an ecosystem could not exist.

[7] Although, as we argue in the next chapter, in our opinion symmetry does capture the essence of order construction, and is therefore an apt *epistemological* category.

Furthermore, the same non-linear character of the system dynamics that we are trying to map from cell biology to computing, characterises also our intuitive understanding of complex *economic* processes, and in particular the generalisation of General Equilibrium Theory towards non-linear dynamics discussed in Chapter 4. Thus, non-linearity has a fair chance of becoming a distinguishing and defining characteristic of digital ecosystems, and for this reason we believe it belongs together with the other fundamental ontological categories that we have discussed in this chapter.

2.8 Conclusion

This chapter has explored four theoretical notions that we argue are central to any interdisciplinary theorisation of a digital ecosystem: knowledge, power, democratic process, and non-linearity. The discussion has shown how the first three concepts are interlinked and related to one another, as well as why they are so important as bedrock principles in the social science domain, and fundamental to the task of articulating in theoretical terms the importance of DE research. Mansell (2002: 254) argues

> we should expect 'a new set of guiding principles' or common-sense practices to be interwoven with a new techno-economic paradigm. In so far as they create new asymmetries of power, they can be expected to introduce a new dynamic of social inclusion and exclusion and they may exacerbate existing divisions and distinctions within society. This means that it is essential to explain how and where the new principles are operating, how they alter the operation of existing principles, and what they mean for socially valued human action.

The fourth concept appears to have the potential to revolutionise how we think about computing, and may also have something useful to add to enrich the drastically reductionist mathematical discourse of economics.

As a new socio-technological and economic paradigm, digital ecosystems need be framed by a clear set of guiding principles grounded in both theory and empirical experience. The theorisations of knowledge as discourse, power as distributed and systemic, and democratic processes as defined by both diversity and a drive towards consensus are helpful in that they are transparently harnessed as framing values for digital ecosystems research, and reflect our belief that they are fundamental to any theoretical framework of future research in this area. The complex interaction between knowledge, power and democratic processes within the broader context of information society technology research allows us to understand language and knowledge as discursively and socially constructed, and to recognise the structural (natural) importance of language as well as the centrality of interacting agents to communication and consensus building. In terms of governance, it is clear that distributed, horizontal models of power are the most appropriate for theorising the ways in which digital ecosystems should be self-governed, and the impacts that the outputs of digital ecosystems research can have upon socio-economics and development policy more broadly. And, in terms of socio-economic development, it is clear that a model of democratic process that recognises both the presence of diversity, and the need for building consensus, must be based on moral equality and consensus-oriented communication. With these principles employed as core theoretical elements of a research framework, it may be possible to work towards a situation where DE research enables dynamics of social, economic and technological inclusion and to minimise existing divisions within society. It needs reiterating that our intention in this discussion is not to somehow unify these very different sets of theorists, but to emphasize how digital ecosystem research needs to create space for a plurality of theoretical views in a pragmatic manner, so as to facilitate community building and a reflexive, critical process of self-organisation. These theories are harnessed here not in order to define how the social world works in an eliminating sense, or to suggest that either should be committed to over the other, but to shine a variety of spotlights on our specific research object – digital ecosystems – in order to illuminate it from the variety of perspectives appropriate and necessary to complex, interdisciplinary, and inter-epistemological research.

The next chapter addresses how we may want to view the implementation of these general research principles as we have performed it during the past 7 years and as the community may wish to continue to extend.

3. A Binary Meta-Epistemological Framework for Digital Ecosystems

3.1 Introduction

In this chapter we address the challenge of constructing a theory that is consistent with the ontology presented in the previous chapter and that can be applied to the practical objectives of digital ecosystems research, sustainable socio-economic development catalysed by ICTs being the first and foremost. To achieve this, we must also define what we mean by 'theory'.

Because as we have argued in D1.2 and D12.1 digital ecosystems research is not only interdisciplinary but is actually 'inter-epistemological', we need to acknowledge in our theoretical framework at least two epistemological positions: the **objectivist** and the **subjectivist**. We take Karl Popper as a reference who relies mainly on the former, whereas we take Anthony Giddens as a reference who has offered a constructive way to reconcile these two positions. At the same time, in digital ecosystems research we also mix theoretical and metaphysical considerations with empirical observation and practical applications. Thus, we need also to acknowledge the presence of useful roles for both **rationalism** and **empiricism**. For this, we find that Popper offers a constructive balance which is compatible with Giddens's work, while Giddens's theory also addresses, albeit to a smaller extent, the **individualism** vs. **collectivism** debate. For these reasons, we believe Popper and Giddens can provide a theoretical core around which past, present and future theoretical constructions in digital ecosystems research can be justified. Finally, we propose **symmetry** and **context-dependence** as fundamental principles of order construction in biology, the former being associated with universalism and invariance of pattern and the latter with open-ended evolution and relativism. Because we wish to develop an evolutionary software environment that is at the same time *reliable* and able to create *new functionality* in response to user behaviour, this fourth epistemological dichotomy seems appropriate to digital ecosystems.

Clearly by relying on these four dichotomies we are oversimplifying the problem and the 'solution', but this is justified by the practical requirements of the research. Digital ecosystems research involves a fair amount of applied and empirical activities in all its disciplines, and for these we need a workable framework by which we can rationalise analytical choices and policy recommendations. In fact, one of the main outputs of OPAALS is a framework that integrates these six meta-theoretical perspectives in a way that explains and rationalises the rest of the digital ecosystems approach. Accordingly, around this core we have built and will finish building in this report connections to a series of other thinkers and currents of thought, showing how they are all 'locally compatible'. By this we mean, for example, that the connections between all the theories could be visualised as the 2-D graph of a semantic network with a particular topology and connectivity. Whereas not all theories would necessarily be easy to relate to all the other theories, proximity on such a graph would indicate a certain level of mutual compatibility.

3.2 The empiricism/rationalism debate

Of Popper's many works we focussed on one of his first, *The Logic of Scientific Discovery*, originally published in German in 1935. In this and the next section we will provide a very short summary of the main ideas, followed by some of the critical points that have been brought against Popper, and we will conclude by highlighting why we think Popper's work is helpful for developing a theory of digital ecosystems.

According to Popper a theoretical system must be deductive, i.e. he rejects the empiricist view that general theories can be inferred from many empirical examples or facts through induction. The reason is quite simple, i.e. that no number of singular statements or examples that follow a particular pattern, or rule, can guarantee that the *next* observation will again comply with the same pattern. Therefore, the inference of a universal law from many empirical observations is logically faulty. By contrast, Popper calls his approach the "deductive method of testing", whereby a hypothesis can be empirically tested only *after* it has been

advanced (Popper, 2002: 7). To arrive at a workable epistemology compatible with the deductive method of testing, Popper needs to confront a few problems and propose plausible solutions.

Phychologism is concerned with the reconstruction of the process by which new ideas are created. Popper is not too interested in this activity, which he refers to as the phychology of knowledge. He is interested in the *logic* of knowledge, i.e. in deriving the logical consequences of ideas and arrive thereby at testable hypotheses. For the sake of completeness he quotes Einstein in stating that ideas emerge intuitively, but he is not too concerned about understanding or accounting for this step in the development of his logic of scientific discovery.

He then has to provide a definition for what he means by 'deductive testing' of a theory. He does so by outlining four required steps: (1) checking the theory for internal consistency; (2) checking the logical form of the theory (e.g. empirical/scientific vs. tautological); (3) comparison with other theories; and (4) testing and conclusions or implications derivable from the theory against empirical/experimental evidence.

The next problem is related to step (2) above and is called the problem of demarcation, or the problem to distinguish empirical science on the one hand, and mathematics and logic, as well as metaphysical systems, on the other (Ibid: 11). This is a long-standing issue related to debates surrounding the ontological status of theories. The empiricists and positivists regard only empirical facts as 'real', and anything that cannot be tested by experience and therefore belongs to metaphysics as "nonsensical twaddle", with an intentionally derogatory connotation (Ibid: 13). The way positivists attempt to distinguish (i.e. demarcate) valid scientific theories from metaphysics is by requiring the reducibility of the former to atomic or individual "statements of experience" that can be verified empirically. According to Popper this is just another way to phrase the demand for an inductive logic, and therefore it is equally faulty. As a consequence, this approach cannot lead to an effective criterion of demarcation.

Moreover, Popper argues that the positivists' attempt at eliminating metaphysics ends up eliminating natural science along with it. Since he rejects the principle of induction, in fact, the reverse implication is that scientific theories cannot be reduced to individual statements of experience. Hence, consistently with the positivist philosophical programme, scientific theories become "meaningless" as well. By contrast, Popper intention is not to overthrow metaphysics but, rather, "…to formulate a suitable characterisation of empirical science, or to define the concepts 'empirical science' and 'metaphysics' in such a way that we shall be able to say of a given system of statements whether or not its closer study is the concern of empirical science". The consequence of the need to *define* these concepts in such a way that makes demarcation possible is that Popper's criterion of demarcation has to be regarded as "a proposal for an agreement or convention" (Ibid: 15). Thus, it is interesting to note that this particular aspect of Popper's theory, which is generally regarded as objectivist, relies on a significant social constructivist component.

Rather than dwelling on the metaphysics by rejecting it or supporting it, Popper is happy to acknowledge that metaphysics has played an important role in the development of new scientific theories, but he sees the scientific method as arising from a particular "concept of empirical science". Popper lists three requirements that such an empirical theoretical system needs to satisfy:

1- it must represent a *possible* world
2- it must satisfy the criterion of demarcation, i.e. it must not be meta-physical but must represent a world of possible *experience*
3- it must represent *our* world of experience

The system that represents our world of experience is distinguished by the fact that it has been subjected to tests, and has withstood those tests. Here Popper says, however, that the verification of a statement of empirical science is impossible to achieve, because such verification would need to rely on breaking down such statement into singular statements verified by experience. But this is induction in reverse, and therefore just as faulty. Therefore, to solve this problem Popper is forced to turn the problem around: rather than attempting to verify the truth of empirical statements, we can only disprove them. In other words, "it must be possible for an empirical scientific system to be refuted by experience" (Ibid: 18). This

is the criterion of falsifiability, which can be employed as a criterion of demarcation that can tell us whether a system of statements constitutes an empirical scientific theory or not.

This criterion provides us with a test by which we can determine whether the elements of a *theory of digital ecosystems* are legitimate or not, because the requirement of practical relevance of the theory implies that we can only accept theories that are falsifable, i.e. that can be subjected to empirical tests. Figure 3.1 depicts the relationships and relative importance between the main concepts in Popper's philosophy.

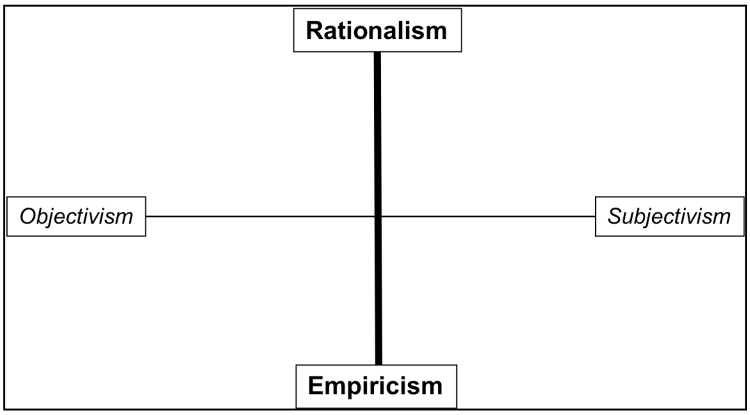

Figure 3.1: The main dimensions of Popper's philosophy of science

The understanding of empirical science afforded by Popper helps us highlight the additional challenge posed by social theory. In particular, Giddens (1984: xxxiii) notes:

> There are no universal laws in the social sciences, and there will not be any – not … because methods of empirical testing and validation are somehow inadequate but because … the causal conditions involved in generalisations about human social conduct are inherently unstable in respect of the very knowledge (or beliefs) that actors have about the circumstances of their own action.

Elsewhere, Giddens (1991: 206) elaborates:

> There are no patterns of universal causation in the social sciences – that is to say, conditions in which circumstance X will, and must, always be followed by circumstance Y – because all causal connections in human social life are mediated in one way or another by agents' knowledgeability and agents' reasons.

In other words, Giddens is arguing that because the "theories and findings of social science cannot be kept wholly separate from the universe of meaning and action which they are about" (Giddens, 1984: xxxiii), they are inherently multiple and defined by context (space and geography), subjectivity and time (history). A shorter way to say this is that, **unlike physics, in social science the 'object of study' has *opinions* about what is being said about them**. All social science is therefore defined by "mutual interpretive interplay" between the theory and action.

Vessuri echoes this, arguing that "the practices of social science involve multiple readings of social reality" (Vessuri, 2002: 137). Underlying this view of social theory is an acknowledgement of its "theoretical pluralism and the intellectual provisionality", which should be understood as "legitimate features of the modern scientific enterprise" (ibid.). In other words, contemporary social theorists recognise that there exist serious constraints on the rhetorical force with which they can present "a uniform concept of reality as superior to all competing concepts" (Vessuri, 2002: 137). It is exactly a competing and empirically contextualised view of social reality that social scientists seek to explore and theorise, despite an increasingly sophisticated acknowledgement about the "impossibility of a single 'truth'" (Vessuri, 2002: 139). Giddens (1984: xx) argues that social theory should first and foremost concern itself with "reworking conceptions of human being and human doing, social reproduction and social transformation".

Theory therefore exists in order to be applied to and to help frame and make sense of complex real-world social issues. Vessuri (2002: 147) argues

> Despite their lack of authoritative 'answers' to the most complex problems, the social sciences have much to offer local, state, national and international agencies. Their evidence and theories provide ways of making sense of the world – no minor achievement in today's complicated, multidimensional world.

Social theory can be productive and offer value beyond the intellectual projects of philosophy and interpretation by feeding into and informing policy. Giddens (1984: xxxiv) outlines three factors that distinguish the "best and most interesting ideas in the social sciences". The first entails fostering debate about social processes. The second involves contributing to theories that constitute those social processes. The third implies the ability to encourage considered reflection by social actors on theories in use and how they can be articulated and improved upon. The consequences of social theory thus relate to policy, which emerges "from interaction rather than from a rational analysis of alternatives" (Vessuri, 2002: 139), and to the broader impacts of ideas upon social processes and reflexive involvement therein. The next section addresses the implications, from a meta-theoretical level, of the multiplicity of social theory.

3.3 The objectivism/subjectivism debate

The preceding summary of Popper's theory has outlined some of the details of the relation between empiricist and rationalist philosophies. As well as this, a further key dimension to our theoretical framework needs articulation: objectivism/subjectivism. In the long and complex history of social theory and philosophy, two strong and opposing traditions have theorised the social world from almost diametrically opposing stances, and clearly recognisable traces of these positions remain evident in the broader debates that characterise the social sciences. Giddens (1995: 11) argues that the debates between positivism and hermeneutics in social theory are in "some sense concerned with the relation between the natural and social sciences". This is because positivist philosophers looked to the natural sciences as a model for logic, whereas interpretivist philosophers saw the natural sciences as irrelevant to the study of human social action. Furthermore, Giddens notes that a division between objectivism and subjectivism is a dualism deeply entrenched in social theory: the former considers that "the object (society) predominates over the subject (the knowledgeable human agent)" (Giddens. 1984: xx); the latter "influenced by hermeneutics or phenomenology were able to lay bare major shortcomings" (ibid.) of the former.

Positivist sociology has been said to originate in the 'positive philosophy' of Auguste Comte, and can be said to represent a "'natural science of society' which can hope to reproduce a system of laws directly similar in form to those achieved in the natural sciences" (Giddens, 1995: 137). We do not have the space in this deliverable to provide an exhaustive account of the debates within social theory as positivism evolved (see Chapter 5 of Giddens, 1995 for a comprehensive critical summary). What is important to note, however, is that according to Comte the essential attributes of positivism can be noted as

- an orientation to reality, utility, certainty and precision (ibid.: 140);
- a commitment to "the essential importance of empirical observation" (ibid.: 142);
- and the fact that he defined no place for the reflexive subject (ibid.: 150).

Giddens argues that Comte's philosophy influenced Durkheim, who also held that "the aim of sociology was to arrive at the formulation of principles that had the same objective status as natural scientific laws" (ibid.: 145) as well as the Vienna school, to which Karl Popper had close intellectual contact, even though he was not a member thereof (ibid.: 166). Although Popper insisted often that he was not a 'positivist' (see Farr, 1983 and the ensuing debate in the same edition of that journal), some similarities between his philosophy and that of logical positivists indebted to Comte can be noted:

> Popper shares the conviction that scientific knowledge, uncertain though it may be, is the most certain and reliable knowledge to which human beings can aspire; his endeavour to establish clear criteria of demarcation between science and pseudo-science has much of the same impetus as the concerns of the logical positivists to free science from mystifying, empty word-play; and, like [them], his characterisation of science is a

> procedural one: science is separated from other forms of tradition in so far as its theories and findings are capable of being exposed to empirical testing and therefore to potential falsification (Giddens, 1995: 167).

Tucker (1998: 41) notes similarities between the theories of Popper and Talcott Parsons (who rejected autopoietic ideas), famous social systems theorists who predated Luhmann. Essentially, Tucker argues, neither Parsons nor Popper see any essential difference between the study of nature and the study of society. Popper, however, identified the problem of the misinterpretation of the logic of natural science by social scientists such that they believed they could decipher the laws of history and society. Relatively speaking, Popper advocates an "interpretive approach to scientific analysis", which starts with the problem rather than the theory. Nevertheless, he "postulates an objective world of facts that cannot be denied, and to which all scientific theories aspire" (Tucker, 1998: 41). Giddens notes that falsification is not as simple as Popper suggests, as underlying theoretical approaches will inevitably influence the paradigm of the observations (Tucker, 1998: 42-3). Furthermore, Giddens has criticised Popper's ignorance of the role of subjectivity and skilled, reflexive agents in reproducing society (Tucker, 1998: 43). This leads us necessarily to a discussion of theories of subjectivism.

Popper's view on the social sciences can be summarised as a preference for "purely objective method". Jurgen Harbermas, "engaged in a critical re-examination of the … legacy of positivism in the twentieth century" (Bernstein, 1983: 42) critiques this position, arguing that the "objectivity of natural science could not be transferred directly to the social sciences, since the latter were concerned with a pre-interpreted universe of occurrences: that is to say, a social world in which the categories of experience were already formulated by and in the 'meaningful conduct' of human subjects" (Giddens, 1995: 178). In other words, pure observation of a social event involving human actors was insufficient, and more attention should also be placed on hermeneutic understanding.

The subjectivist position can be extrapolated through a brief summary of philosophical hermeneutics, with reference to one of its foremost representatives, Gadamer. Hermeneutics essentially takes as fundamentally significant the various forms in which human understanding (of art, communication, social life) manifests itself (Gadamer, 1976: 18). Central to this position is language (or as Gadamer (1976: 19) puts it, "the universal phenomenon of human linguisticality"), and the ways in which it mediated individual understanding and interpretation of social experience. Ultimately, the argument of the hermeneutic position is that human understanding of everything in the world is carried within language. Rooted thus in philosophies of the aesthetic and rhetoric, hermeneutics implies that "the grasping of the meaning of the text takes on something of the character of an independent productive act" (Gadamer, 1976: 24). In the context of social science theory, hermeneutics reflects the position that knowledge is rooted in the experience, understanding and interpretive ability of the individual agent, rather than in the overarching structures of society. Gadamer (1976: 28) claims:

> My thesis is … that the thing which hermeneutics teaches us is to see through the dogmatism of asserting an opposition and separation between the ongoing, natural 'tradition' and the reflective appropriation of it. For behind this assertion stands a dogmatic objectivism that distorts the very concept of hermeneutical reflection itself. In this objectivism the understander is seen … not in relationship to the hermeneutical situation and the constant operativeness of history in his own consciousness, but in such a way as to imply that his own understanding does not enter into the event.

Gadamer's project can be summarised as aiming to underline and explicate "the practical implications of hermeneutics and its significance for understanding the limits and role of the social and political disciplines" (Bernstein, 1983: 42). Ricoeur (1990: 300) comments that hermeneutic philosophy declares the amplitude of its aim (universal language) at the same time that it announces the locality of its point of departure (individual experience). "Thus hermeneutics has an aim which precedes and surpasses any science" (ibid.). The project of interpretivist theory was to show that those forms of knowledge dismissed as pseudo by the formal and natural sciences because they could not be reduced to the canons of scientific discourse were legitimate, and that they were dismissed due to the failure to question the very framework of the underlying, unacknowledged assumptions of the disciplines (Bernstein, 1983: 48-9). So, understanding that the subjectivist, hermeneutic position is an opposing part of a dialectic that situates

objective positivism at the other end, the question arises as to whether, and if so how, these epistemologies are reconcilable. One theorist who attempted this was Anthony Giddens.

Less in order to resolve the divide, and more to constructively theorise the interdependencies of structure (object) and agency (subjectivities), Giddens developed, over the course of at least a decade (1976-1984) (Bryant and Jary, 2001: 11), the theory of *structuration*. In the discussion of complex adaptive systems in D12.1, structuration was noted as an example of social theory that had proved useful to many social scientists engaged in theoretical and empirical questions that demand a nuanced understanding of the interplay between agency and structure. Indeed, Giddens opens his influential account by expounding "the divisions which have separated functionalism (including systems theory) and structuralism on the one hand from hermeneutics and the various forms of 'interpretative sociology' on the other| (Giddens, 1984: 1). It is important to note that his theory of structuration addresses ontological rather than epistemological concerns – "what is at issue is how the concepts of action, meaning and subjectivity are to be specified, and how they are related to notions of structure and constraint" (Bryant and Jary, 1991: 10). Ultimately, Giddens intended structuration theory to offer "a conceptual scheme that allows one to understand both how actors are at the same time the creators of social systems yet created by them" (Giddens, 1991: 204). Cohen (1989: 2) comments that structuration "provides ontological resources for the formulation of empirically oriented theory and research". Thus, as a theory, structuration should be understood as the means to frame research practice. **The appeal of structuration for digital ecosystems research is that it provides a balance between the emergence of institutions through processes that are reminiscent of 'bottom-up' social constructivism, and the effect these same institutions have on socio-economic action through processes that are reminiscent of 'top-down' and history-dependent structuralism.** In other words, implicit in structuration is not only a useful integration of objectivist and subjectivist understandings, but also a measure of reconciliation between the individualist and the collectivist explanations of socio-economic action, athough it is not emphasised as much by Giddens himself. This is shown graphically in Figure 3.2.

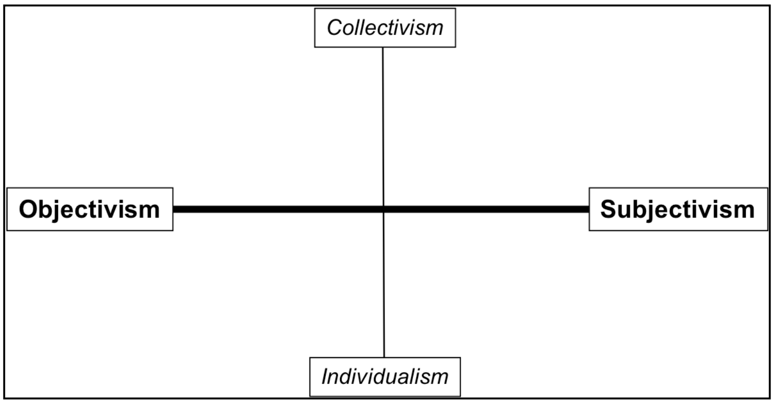

Figure 3.2: The main dimensions of Giddens's philosophy of social science

As further evidence of the way in which Giddens argues that structuration theory successfully mediates between concepts of agency (subjectivism) and structure (objectivism) is his concept of the double hermeneutic. This is unique to the social sciences, and describes the fact that all social research (whether framed by objectivist theories and principles and/or employing quantitative methods) "has a necessarily cultural, ethnographic or 'anthropological' aspect to it" (Giddens, 1984: 284). The double hermeneutic "derives from the double process of translation or interpretation which is involved [in social research]. Sociological descriptions have the task of mediating the frames of meaning within which the actors orient their conduct" (ibid.). In other words, social theory can be considered a different language that is used to express things about the social world that social actors in that world already know, and express in their own language. It is the task of social research and theory to mediate between those languages, and interpret both simultaneously – hence the double hermeneutic. As well as this, it should be noted that it also addresses, implicitly, the tensions between individualist and collectivist notions of action and agency (the more explicit theoretical implications of this will be addressed at length in Chapter 2).

3.4 The symmetry/context-dependence debate

Symmetry, understood in general as invariance with respect to some transformation, is one of the most important organising principles of physics, if not the most important. This is a consequence of the regularity of the properties of the physical universe and of the physical laws that govern it, which is reflected in the properties of the mathematical models of physical systems. For example, since the invertible transformations of a mathematical object that leave some feature of its structure invariant form a group (Stewart, 1989: xxvii), the mathematics of regularity and pattern are grounded in algebra. Thus, symmetry is an invaluable epistemological compass for the physical scientist and the applied mathematician and a 'universal spanner' for the engineer that underpins the predictive properties of quantitative scientific theories and the intuitive process of engineering design, respectively.

But biology is not so easily stowed away. As we have already discussed in Dini et al. (2008a,c), in spite of a recognisable topological regularity of form across whole classes of species, the variability of life-forms is astounding and ever-increasing. More to the point, our efforts to understand and, optimistically, model biological behaviour at all scales are a consistent humbling experience. Evolution has made adaptation to different contexts the predominant organising principle in biology, and the universal order construction mechanism. In spite of important landmarks such as D'Arcy Thompson's *On Growth and Form* (1992) and Benoit Mandelbrot's *The Fractal Geometry of Nature* (1983), in computer science "bio-computing" elicits almost exclusively associations to evolutionary computation, probably because of John Holland's similarly important 1975 book on genetic algorithms (Holland, 1975). Thus, our last dichotomy pits these two epistemological categories of biology as polar opposites, as shown in Figure 3.3.

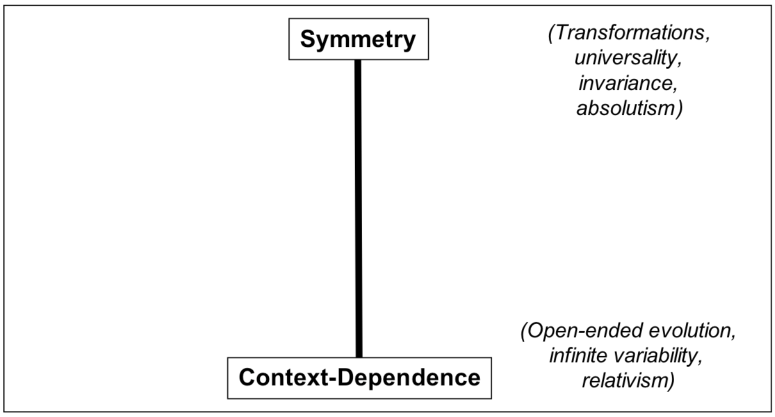

Figure 3.3: The polarisation of biological epistemology

Rather than exploring this dichotomy in the humanities and social sciences, we feel that in this chapter and the previous we have already deployed all the machinery we need to address the socio-economic and socio-technical aspects of digital ecosystems. Thus, we are more interested in applying this dichotomy to biology and in particular to bio-computing. In particular, the whole edifice of gene expression computing that we are in the process of building is founded on the relevance of symmetry to biology, through the mathematical formalisation of regularities in pattern and behaviour. As we have argued elsewhere, such regularity is desirable from the point of view of the reliability of physiological and metabolic functions in biology and of the reliability of software execution in software engineering.

At the same time, biology relies on the openness of the ecosystem and on what is generally called 'open-ended evolution' to support the continuous emergence of new life forms. This is an essential property of a digital ecosystem, which can in principle enable the software to generate new structures and algorithms to track the changing requirements and behaviour of the users. We must eventually reach an effective evolutionary architecture. However, as we have argued repeatedly, before we can achieve effective evolutionary behaviour we must understand how gene expression mechanisms can be migrated to software. In the context of a discussion of ontogeny and phylogeny in the DBE project, already three years ago (Dini, 2006) we had argued that autopoiesis offers an interesting way to balance structure and context, as shown in Tables 3.1 and 3.2.

Table 3.1 Ontogeny and phylogeny according to neo-Darwinism			
	Cause, instruction	*Mechanism*	*Effect*
Ontogeny	DNA	GENE EXPRESSION	METABOLIC CYCLES, MORPHOGENESIS
Phylogeny	ENVIRONMENT	NATURAL SELECTION	GENOME

Table 3.2 Ontogeny and phylogeny according to autopoiesis			
	Actor 1	*Mechanism*	*Actor 2*
Ontogeny	DNA	STRUCTURAL COUPLING	CELL
Ontogeny	ENVIRONMENT	STRUCTURAL COUPLING	ORGANISM
Phylogeny	ECOSYSTEM	NATURAL DRIFT	SPECIES

Regardless of whether we describe the various phenomena through Darwinism or through Structural Coupling, we seek an integration of gene expression and evolutionary computing that is analogous to what DNA has been able to achieve: the *same molecule* is a carrier of hereditary traits across generations whilst also guiding the morphogenesis and metabolism of the individual organism. Similarly, in digital ecosystems research we need to balance the general principles that apply to all digital ecosystems with the properties that depend on each specific regional context. A good part of our research so far has been precisely to develop a methodology that will achieve just that, as discussed in Chapters 4, 5 and 6.

3.5 Critique of our previous theoretical work on digital ecosystems

The meta-theoretical framework discussed here has many things in common with previous attempts at building an integrated theoretical framework for digital ecosystems (Dini et al, 2005; Dini, 2007a; Dini and Nachira, 2007), which is summarised well by Figure 3.4, adapted from Hollis (1994). In this report we transcended this figure by going beyond an epistemological framework that is mainly relevant to social science by introducting new dimensions and considerations that are relevant also to computer science and natural science. Although what we have discussed so far does not contradict this figure, by bringing Popper into the mix we have introduced explicitly the empiricism/rationalism dichotomy, which was accounted for by Figure 3.4 only indirectly. The advantage of this extension of the framework is to provide a dimension that is compatible with digital ecosystems **practice**, which has always been empirically grounded and which aims to inform policy and software development.

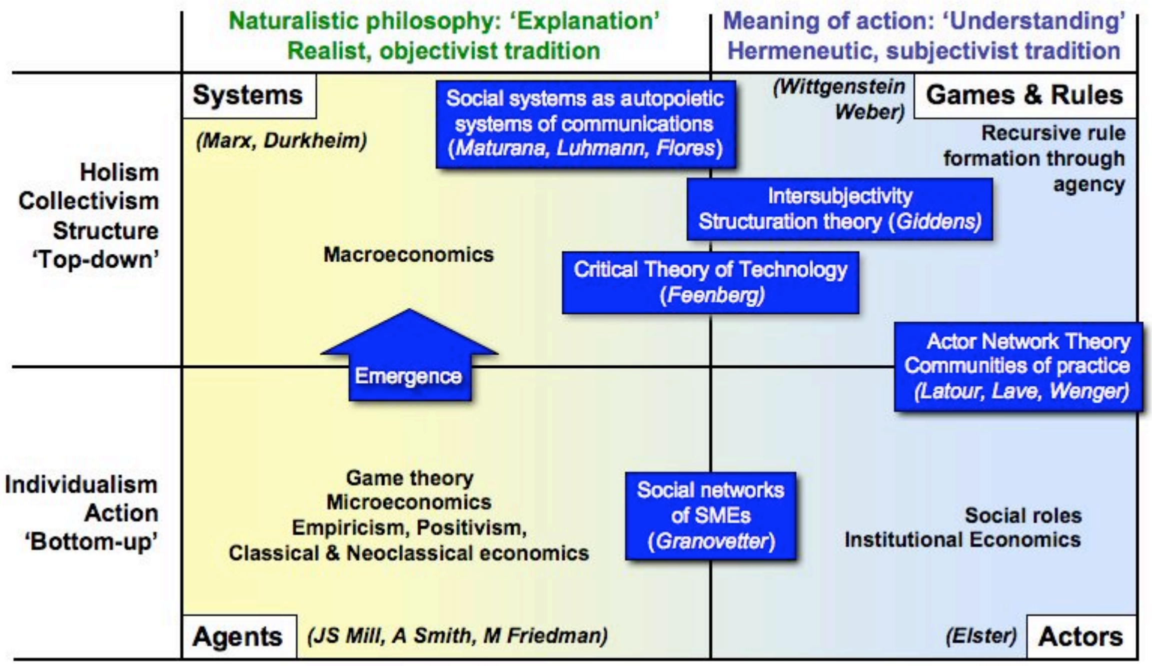

Figure 3.4: Map of social science adapted from Hollis (1994)

3.6 Conclusion

The four theoretical dimensions outlined in this section – rationalism/empiricism, objectivism/subjectivism, individualism/collectivism, and symmetry/context-dependence – can thus be considered to provide a meta-theoretical framework which outlines the view on theory that guides the development of a set of epistemological principles that guide digital ecosystems research. It should be noted that Popper de-emphasises the importance of the tensions and complexities of subjectivism/objectivism (hence being noted as an objectivist), and Giddens, in his work on structuration, tends to de-emphasise the importance of individualism/ collectivism in favour of theorising and negotiating the relations of subjectivism and objectivism. In his later works, Giddens (1991b) turns his attention to exploring in great detail the notions of self-identity and life politics, which take the individual as the focus of social action, and the implications for social theory. Structuration, on other hand, can be understood to be a fundamentally collectivist theory, which aims at explaining how communities of social actors contribute to, and are affected by, social structure. Nevertheless, structuration can be employed to explain socio-economic action at both individual and institutional levels, and can hence be used to rationalise the kind of balance between individualism and collectivism within digital ecosystem research and within digital ecosystems themselves.

In summary, our epistemological framework is now able to provide the following:

- A rationalisation by which candidate theories or extensions to digital ecosystems theory can be legitimately assessed through empirical tests and observation (Popper's falsifiability).
- A methodology rooted in empirical qualitative and quantitative data that, through integration with Giddens's structuration, can combine the empirical testing of theories with social constructivist multi-stakeholder processes for the phased introduction of digital ecosystems in different regional contexts.
- An epistemology based on structuration that puts processes of institutionalisation and of technology development on a similar footing, where Marxian structuralism is balanced by individual action and social constructivist processes.
- A subjectivist and reflexive discourse that provides the foundation for the shared construction and equitable negotiation of a governance framework for digital ecosystems communities.
- A compound epistemology of order construction in computer science that leverages nature's symmetries whilst remaining open to new forms, and hence able to interface to human expression and behaviour.

Through the discussion in the deliverable thus far, we have brought together a variety of orthogonal theoretical viewpoints. Our intention with these often rather controversial juxtapositions was not to try and force these points of view together in a false way in order to suggest that a new, convenient synthesis is possible, but instead to show the necessity of working with and exploring a variety of theoretical viewpoints in order to find new, creative ways to locate, ontologically and epistemologically, and construct, through the process of reflexive research, an integrated theory of digital ecosystems. Our aim with this theory (or the beginnings of it as outlined in this deliverable) is not to explain the social world but to work with ideas that can help to clarify, and at times complicate, digital ecosystem research so as to make it as fruitful and widely applicable as possible. The meta-theoretical framework outlined in the four bullet points above is equally applicable to all the dimensions of OPAALS research, which should be understood as four poles of epistemological activity in constant dialogue with each other through a fully-connected network: the construction of natural science theories and models of the cell, the construction of social, political and economic theories, applied processes and frameworks relevant to the sustainable socio-economic development of specific regional contexts, and the construction of software architectures and algorithms that benefit from the biological insights and from a deeper understanding of the role of technology as an extension of our languages and as a bearer of our cultural values.

In the rest of this report we will outline how our past, current, and future activities of digital ecosystems research fit this meta-theoretical framework. We will strive to show how the different elements of our theories and practices reinforce each other when they are understood through this framework, leading to a diverse and tolerant community of ideas, people, and technologies that, we hope, will far outlive the project.

4. Integrating Biological and Social Science Perspectives

4.1 Introduction

Biology as basic to and an integral part of social science and sociology in particular has a long and distinguished, though somewhat controversial, history. The idea that sociology has to be based on biology recalls the Spencer-Ward hierarchy of the sciences which suggests that biological foundations are necessary for sociological analysis. As far back as we can go in the history of social science, we can see that there is no period which in some way or another did not relate biology and social sciences. From Plato to Hobbes, Aristotle to Comte, Aesop or Saint Paul to Spencer, the metaphor of the organism figures as a commonplace in representations of society. Elements of the classical social theorists' writings are centred on issues of differentiation, integration, and social transformation. It is largely these concepts that have dominated the writings of most social theorists.

A greater attention has been given to the development and transformation processes in effect, on explicit (as in Durkheim, 1893 or Spencer, 1891) or implicit (e.g. late Parsons, 1971) analogies to organic development. Herbert Spencer shows four types of parallelism between biological organism and society (Spencer, 1891). However, in later periods, although sociological approaches draw their inspiration from biology, they do not discuss in any sense the social implications of modern genetics or the synthetic theory of evolution. One of the chief reasons for this probably lies in the reaction to social Darwinism. The Social Darwinists stressed simple unilinear social evolution, automatic progression from stage to stage of social development, and explained the mechanisms of social evolution in such terms as "struggle for existence" and "survival of the fittest". The evolutionary theory of the Social Darwinists (when applied to social and cultural phenomena) created a popular faith – "upward and onward" – in social progress, but the events of the Twentieth Century (two devastating World Wars) soon shattered the illusions of perpetual evolutionary progress.

Roy Bhaskar in his Critical Realism argues for biological and natural science approaches for social science (Bhaskar, 1998). Bhaskar suggests that transcendental realism is the only basis on which to sustain the intangibility of experimental activity and practical application of scientific laws. For laws cannot be constant conjunctions of events, as positivists believe, because our experience is that conjunctions are rarely constant. Instead laws are grounded in real natural mechanisms which produce sequences of events but only manifest themselves as empirical invariance in normally artificially produced closed systems. Bhaskar proposes that human sciences can exactly be sciences *in the same sense* as natural sciences but not necessarily *in the same way*. This is consistent with our adoption of Popper's falsifiability paradigm as one of the building blocks of a theory for digital ecosystems, which relies to a very significant extent on the social sciences. Biological understanding of social phenomena also has been advocated by Jeffery C. Alexander in his neo-functionalistic theory (Alexander, 1998) and by Margaret Archer in her Morphogenetic approach to study social phenomena (Archer, 1995).

In this chapter our focus will be on biological approaches in social science proposed by Luhmann and Giddens, followed by a discussion of 'lessons learned' from biological ecosystems.

4.2 Luhmann and the biological roots of social science

In the social sciences, one of the main representatives of socio-biology (self-organisation) theory is Niklas Luhmann. Luhmann was one of those scientists who have shown the link between biological sciences and social sciences. However in doing so, Luhmann conceptually eliminates human actors from society and therefore is not subject to falsification. The importance of human actors in society has been elaborated by Giddens in his work on structuration theory. But before going to Giddens in the following sections we will discuss Luhmann and his approach to self-organisation theory.

4.2.1 Self-organising systems and autopoiesis

Self-organisation is a process where a system assembles itself with the help of its own logic and components, or with the help of logic and components resident in its environment. Self-organising phenomena do not have to be centred on a particular system, they can be more pervasive, as in the self-organisation of an ecosystem, whose precise boundaries are always difficult to define uniquely. Autopoiesis, which was inspired by the study of the cell, adds a twist in that it is focused on a particular system with a well-defined boundary (i.e. the cell membrane). In addition, the system produces itself based on an internal logic. Autopoietic systems are their own reason and cause; they produce themselves (*causa sui*). In an autopoietic system, new order emerges from the old system. This new order can't be reduced to single elements; it is due to the interactions of the system's elements, a phenomenon that is called organisational or operational closure (Dini et al, 2008c). Hence, a self-organising system, and even more so an autopoietic system, is more than the sum of its parts. The process of the appearance of order in a self-organising system is termed *emergence*.

Some important characteristics of a self-organising system that are mentioned in the literature and are summarised here are (Eigen and Schuster 1979; Haken , 1983; Nicolis and Prigogine 1989; Prigogine 1980): (1) Systemness, (2) Complexity, (3) Control parameters, (4) Critical value, (5) Fluctuation and intensifications, (6) Feedback loops and circular causality, (7) Non-linearity, (8) Bifurcation points, (9) Selection, (10) Emergence of order, (11) Information production, (12) Fault tolerance, (13) Openness, (14) Symmetry breaking, (15) Inner conditionality, (16) Relative chance, (17) Cohesion, (18) Hierarchy, (19) Globalisation and Localisation and (20) Unity in Plurality (Generality and Specificity). The concept of emergence is the central notion of self-organisation concepts. The physical basis of self-organisation have also been discussed and summarised in DBE deliverable D18.1 (Dini and Berdou, 2004).

Self-organisation theory considers nature as dynamic and is hence opposed to the classical Newtonian worldview that characterises nature and society as strictly determined, immutable, conservative, reducible to mechanics, and stable. The idea of self-organisation is not new in social sciences. The earliest writings on self-organisation in social sciences are found in the works of Marx and Engels. In biological sciences Humberto Maturana and Francisco Varela (1992) have applied self-organisation theory to find a consistent definition of life. They say that living systems are biologically self-organising in the sense that they permanently produce themselves, their parts, and their unity. They term such self-producing systems *autopoietic* (*autos* = self, *poiein* = to make something). According to the theory, a living being is an operationally closed system, that is, a self-referring system that operates on its own states. The process which takes place within this system produces components that interact in such a way that they maintain the same process that produces these components (Maturana, 1980; Varela, 1992). Thus, the process is autopoietic (self-creating) and is aimed solely at its own maintenance, while the observable spontaneous activity is an external manifestation of this process. According to Maturana and Varela a living system (re)produces itself. It uses its own elements to produce further elements. A living cell, for example, reproduces its own molecules, such as lipids, proteins, and so on, they are not imported from outside (Varela et al., 1974: 188).

Maturana and Varela's model of autopoiesis is an idealisation in the sense that it chooses to ignore the signals that enter the cell from the outside and the signals that the cell sends to the other cells in its proximity. However, it is still a very useful model and an important milestone in the conceptualisation of life processes. In this idealisation, all operations are produced by the system itself and all operations of autopoietic systems are processes of self-reproduction. In this sense, autopoietic systems are *operationally closed*. The autopoietic operations are only produced internally, they do not come from the outside – that is, only the cell itself can produce its specific molecules – and vice versa: all operations of an autopoietic system contribute to the reproduction of the system itself and not to any other system outside. It is important to note that the system's operational closure, however, does not imply a closed system model. It only implies a closure on the level of its operations in the sense that no operations can enter or leave the system. Nevertheless, autopoietic systems are also open systems in the sense that all autopoietic systems have contact with their environment (*interactional openness*). The contact with the environment, however, is regulated by the autopoietic system itself; the system determines when, what and through which channels energy or matter is exchanged with the environment.

4.2.2 Luhmann and autopoiesis in social systems

The idea of social self-organisation is frequently associated with the works of Niklas Luhmann on social systems. Luhmann (1995) conceives society in functional terms, applies Maturana's and Varela's autopoiesis concept sociologically, and sees society as a self-referential system with communications as its elements. Luhmann wrote:

> If we abstract from life and define autopoiesis as a general form of system building using self-referential closure, we would have to admit that there are non-living autopoietic systems, different modes of autopoietic reproduction, and general principles of autopoietic organization which materialize as life, but also in other modes of circularity and self-reproduction. In other words, if we find non-living autopoietic systems in our world, then and only then will we need a truly general theory of autopoiesis which carefully avoids references which hold true only for living systems. (Luhmann, 1986: 172)

Luhmann suggests that we can speak of autopoiesis whenever the elements of a system are (re)produced by the elements of the system. According to him this criterion is met by two non-biological types of systems: psychic systems and social systems (with its three sub types-society, organisation and interaction). However before applying the concept to social and psychic systems Luhmann first *abstracted the concept to a transdisciplinary level.* We cannot examine the abstraction in detail here, but will just highlight two important modifications: the temporalisation and the deontologisation of the concept of element.

Applying the general concept of autopoiesis to the study of particular systems requires specific operations to be identified on the basis of which the system reproduces itself. If the system is to be clearly distinguished from its environment, it is necessary to identify a *single specific* mode of operation. In other words, the researcher can only use the concept of autopoiesis if he or she can specify a single operation on the basis of which the system is reproduced. For example, according to Luhmann, the 'human being' (consisting of live tissue, of a brain and of a psyche) cannot be treated as an autopoietic system as one cannot specify any *single specific* operation on the basis of which this system as a unity would be (re)produced and thus differentiated from its environment. Rather, the 'human being' has to be treated as consisting of four different types of autopoietic systems that do not form a unity (cells, brain, organism, psychic system).

According to Luhmann the psychic system can be conceptualised as an autopoietic system reproducing itself through thoughts: it is a system of thoughts that produces its thoughts through its (network of) thoughts; every thought (independently of its 'content') that is produced through the system of thoughts reproduces the psychic system. The psychic system is clearly operatively closed: no thought can enter the psychic system from outside—for example, the thought in the mind of one person cannot enter into the mind of another person. Though the internal thought processes are influenced by perturbations (synonymously: irritations) from the environment, but what thoughts are 'triggered' from outside depends on the specific thoughts already present in the psychic system. As long as any thoughts (no matter what they are about) are produced, the 'boundary' between system and environment is reproduced. However, as soon as the thought processes stop, the 'boundary' between system and environment disappears; which is equivalent to saying that the system disappears. Analogous to the psychic system, Luhmann conceptualises the social system as a system that reproduces itself on the basis of one specific mode of operation. In contrast to all existing social theories, he chooses not person or action as the basic social element but *communication* (or, more precisely, the communicative event). According to Luhmann, only communication (neither person nor action) fits the concept of autopoiesis. He writes:

> Social systems use communications as their particular mode of autopoietic reproduction. Their elements are communications which are recursively produced and reproduced by a network of communications and which cannot exist outside of such a network. (Luhmann, 1986: 174)

In order to understand this conceptualisation of social systems, we need to clarify Luhmann's *concept of communication*, which is considerably different from the conventional notion of communication as an asymmetrical process of transferring meaning or information from a sender to a receiver. Communication according to Luhmann consists of three components: information, utterance and understanding, each of which is conceptualised as selection. Luhmann defined information as a selection

from a repertoire of possibilities. Every communication selects what is being communicated from everything that could have been communicated. With utterance Luhmann referred to the form of and reason for a communication: how and why something has been said. Understanding is conceptualised as the distinction between information and utterance: for a communication to be understood the information has to be distinguished from the utterance. The understanding as distinction between utterance and information ultimately determines the utterance and information, and thus the communication. An important point in Luhmann's concept of communication is that the three selections form an 'insoluble unit'. To be sure, this unit can be divided analytically into its three components, but only as a unit does it constitute a communication. Thus the concept of communication is free of reference to any underlying subject. In this sense, the communication can be said to be produced by the communication system rather than by individual actors. In order to understand the self-referential reproduction of the communication system, it is necessary to take a closer look at the concept of understanding. Understanding is implied by connecting communications – in the same way as the meaning of a word in a text is only determined through the following words of the text. Thus, the meaning of a communication – that is, what difference a communication makes for later communications – is only determined retrospectively through the later communications. This depends on acceptance or rejection of communication. The distinction between understanding (as part of the first communication) and the selection of acceptance/rejection (as part of the connecting communication) adds a dynamic element to the social system that bridges the gap from the production of one communication to the next: every communication. Thus in accordance with the general concept of autopoiesis, communications only 'exist' as communications through their relation to other communications. In this sense, one can say that it is the network of communications that 'produces' the communications. Luhmann writes:

> Humans cannot communicate; not even their brains can communicate; not even their conscious minds can communicate. Only communications can communicate. (Luhmann, 2002: 169)

He says that a system can only differentiate itself if it refers to itself and its elements. It generates a description of itself and a difference between system and environment. Self-observation means that a system/environment difference is introduced into the system. All social systems can observe themselves. Luhmann argues that individuals are (re)produced biologically, not permanently by social systems. If one wants to consider a social system as autopoietic or self-referential, the permanent (re)production of the elements by the system is a necessary condition. Hence, Luhmann says that not individuals but communications are the elements of a social system. A communication results in a further communication; by the permanent (re)production of communications a social systems can maintain and reproduce itself.

> Social systems use communications as their particular mode of autopoietic reproduction. Their elements are communication which are recursively produced and reproduced by a network of communications and which cannot exist outside such a network (Luhmann 1988, 174).

For Luhmann, human beings are sensors in the environment of the system. He emphasises communicative processes instead of human beings. Luhmann resolves the sociological problem of how social structures and human actors are related dualistically, but results in inconsistencies. He does not explain how one communication can exactly produce other communications without individuals being part of the system. Without human activity there would be no communication. As Mingers has suggested operationally, one communication may stimulate another, but surely it does not *produce* or *generate* it" (Mingers, 1995). In Luhmann's approach it is the social system rather than humans that act. The reproduction of society is seen as something happening with mechanical inevitability. Luhmann following a functionalism and structuralism standpoint expresses a naturalistic and objectivistic orientation and preeminence of the social whole over its individuals.

For Luhmann, modern society is functionally differentiated: its subsystems are operationally closed networks of communication; each has its own binary code that organises the communications of the specific subsystem. Subsystems form part of each other's environment; they can influence each other in certain ways, but each subsystem is autonomous. The social subsystems are structurally coupled, that is, one subsystem can influence or perturb but never determine the other. What Luhmann does not

conptualise is that moden social systems are networked systems, in such systems it is unlikely that the activity of systems is functionally separated because networks transcend systemic boundaries.

In each social system there is more than one binary code, for example, agriculture as a sub-system doesn't only deal with cultivation issues but also with technological, social, political, economic, juridical questions, and so on. Thus the function of Luhmann's social systems theory is the production of communication in society. Luhmann (2004) argues that a system forms its border by the system/environment difference, that society is the all-enclosing social system of communications and that nature forms the environment of society. His approach is based on an ontology that considers systems as self-centred, endogenous, and operationally closed. In later works Luhmann has accepted the causality between nature and society and shown that both are structurally coupled, but still ignores the role of individuals in his system approach to society which poses a paradox for us. In search of meeting this paradox we turned to Giddens.

4.3 Giddens, agency and duality of structure

> The theorem of the duality of structure occupies a central place in structuration theory precisely because it encapsulated the recursive elements of social life so fundamental to social organization and change. In the sense in which I use it – to refer to the way in which social activities regularly constitute the circumstances that generated them in the first place – recursiveness has only a tenuous connection with the mathematical sense of the term, and I was more influenced by theories of autopoiesis (i.e. of self-producing systems) in biology than by the mathematical concept (Giddens, 1991: 204).

Giddens is one of the few social theorists who have proposed an alternative to dichotomous systems of logic to study social phenomena. Though theoretically promising, the applicability of Giddens's concepts is not without difficulties. Since its publication, Giddens's Structuration Theory has been discussed over its applicability (Held and Thompson 1989). Rooted in biology, the theory is complex, articulating concepts from psychoanalysis, phenomenology, ethnomethodology and action theory, among others (Turner 1991). Based on general propositions and concepts that operate at a high level of abstraction, it gives rise to diverse and sometimes contradictory interpretations (Jones 1997; Jones and Karsten 2003). Still today its application in empirical research is widely recognised as very difficult (Giddens 1989: 296).

In a number of articles in the late 1970s and early 1980s, culminating in the publication of *The Constitution of Society* in 1984, British sociologist Anthony Giddens developed the theory of structuration, which addressed fundamental problems in the social sciences in a way that was unconventional at the time. Moreover, he provided an account of the constitution of social life that departed from and challenged established theoretical positions and traditions (Cohen 1989). It is not our purpose here in this paper to provide a complete overview of Giddens's structuration theory, as a number of comprehensive and authoritative texts on the topic already exist.

Structuration theory is a general theory of the social sciences. Through structuration Giddens tries to resolve the most pervasive and difficult issues in social theory – the relationship between agency and structure. Some of the issues that Giddens seeks to resolve are: How are actions of individual agents related to the structural features of society? How are actions structured in everyday contexts? How are the structured features of actions reproduced?

To examine the dualism between structure and agency, Giddens departed from the conceptualisation of structure as some given or external form. According to him structure is what gives form and shape to social life, but it is not itself the form and shape. Structure exists only in and through the activities of human agents (Giddens 1989: 256). Similarly, he departed from the idea of agency as something just 'contained' within the individual and suggested that agency does not refer to people's intentions to do things but rather to the flow or pattern of people's actions. Giddens deeply reformulated the notions of structure and agency, emphasising that "action, which has strongly routinised aspects, is both conditioned by existing cultural structures and also creates and recreates those structures through the enactment process" (Walsham 1993: 34). He suggested that while structural properties of societies and social systems

are real, they have no physical existence. Instead, they depend upon regularities of social reproduction (Giddens and Pierson, 1998). As a consequence, the basic domain of study in the social sciences consists of social practices ordered across space and time (Giddens 1984: 2).

According to structuration social reality consists of two levels; the level of individualities and the level of totalities. The first level is made up of people whereas the latter consists of abstract social wholes. The people are interpreted as structures and social wholes as structures. Similarly there are two modes of existence of social reality; the mode of potentialities and the mode of actualities. The former relates to the inherent tendencies such as; capabilities, abilities, powers etc, while the latter refers to the processes, development and activities. Structures embrace agents and vice versa. In between the two there exists a third level, the actual manifestation of social fabric. It is the place that stands for the constitution of social life. In a more simplistic sense it is the manner in which all aspects, elements, and dimensions of social life, from simple everyday act to the most complicated of collectivities, are generated through performance of social conduct.

Giddens puts emphasis on the fluid, permanently changeable, fully contingent nature of social reality, whose only true ontological substratum lies in the actions and interactions of human subjects. He turns the static notion of structure into the dynamic category of "structuration" as the description of collective human conduct. "Our life passes in transformation" (Giddens, 1979) and its core content is the constant production and reproduction of society. According to Giddens the structural properties of social system are both medium and the outcome of the practices that constitute those systems. For Giddens the ultimate moving force of structuration is the human actor. He suggests that however, all human actions do not necessarily mean that the outcome coincides with intentions. Rather "Human history is created by intentional activities but is not an intended project" (Giddens, 1979). For Giddens there are always unintended consequences of intended actions. This happens because agents in social situations are conditioned by structures of power relations which are based on resource domination and normative regulations. In real terms the place where both structure and action meet is the manifestation of social fabric and agency is the thing which is actualised. Agency implies the properties of social fabric. It is where structures and agents meet. It is double-conditioned both from above by the balance of constraints and limitations as well as resources and facilities provided by existing structures and power relations, and from below by abilities and knowledge of social members. However, it is not reducible to either of the two; rather, it makes up a new emergent quality. "Structure is both medium and outcome of the reproduction practices. Structure enters simultaneously into the constitution of . . . social practices, and 'exists' in the generating moments of this constitution". Thus there is duality of structure, (and in similar way there exists duality of agents).

Thus, while Luhmann suggests that social systems as autopoietic modes exists only in communication, Giddens shows us that such existence can only be possible through agential coefficients of active human action.[8]

Social systems concepts like self-organization, self-referentiality, autopoiesis and reflexivity have attracted many discussions and debates. Here in this chapter we have tried to follow a more useful approach for our purpose often called heuristics in social research (Sztompka, 2004). This approach is useful in generating relevant concepts, images and models for applied fieldwork. It helps us to probe into "how" rather than "why". It helps us to understand better the ways to construct our applied project "DEAL" and explain why some of it works through social actions that support the emergence of digital networks for knowledge exchange (in our chosen domain).

Luhmann's autopoiesis and Giddens's structuration are convergent in several ways (Hernes and Bakken, 2003) to provide us a heuristic framework to build DigitalEcosystems for Agriculture and Livelihood (DEAL). We rely upon Luhmann and Giddens's convergence on the view of recursivity for building communication loops in social network systems. Both of them view recursivity with structure as being

[8] According to Giddens human history is an unintended consequence of intended human actions. It is therefore logically possible to say that to Giddens human action is the prime force for social change. Thus in Giddens's framework the agential coefficient lies in active human actions (Giddens, 1979).

both a constitutive and constituting entity. That constitution happens through self-reference, something that is reflected in Giddens's reproductions and Luhmann's autopoiesis. The complimentarity of Giddens's approach and that of Luhmann also arises through the time-space compression facilitated by digital technologies (Castells, 2000). Luhmann's (1995) concept of morphogenesis expands Giddens's interaction (1984). We can then explore whether Luhmann and Giddens can be correlated to find the "hows of self-creation of new structures out of existing institutions through recursive communication".

In the next section we shall outline an empirical observation of both these approaches in the context of Digital Ecosystems for Agriculture.

4.4 Digital Ecosystem for Agriculture: DEAL

The DEAL (Digital Ecosystem for Agriculture and Rural Livelihood, www.dealindia.org) is a digital ecosystem platform for knowledge sharing in the agricultural domain for farmers and other stakeholders. The goal framework of the DEAL is focused on interoperability of the information. The goal was to facilitate communication through context-sensitive query processing over heterogeneous information sources. The agenda was to build networks of people supported with multiple ICT tools and technologies, whose interactions with KVK (Krishi Vigyan Kendra = Farm Science Centre) scientists and farmers create new knowledge-based relationships.

Field deployment of the DEAL project was between December 2006 and June 2007. Some further deployment work has been done under the OPAALS project during 2008. We have been conducting studies among participating KVKs from October 2007 onwards. The data used in this paper are taken from the data collected during our field visits at two different time intervals during July-August 2008. The data was collected from five participating KVKs, involving a sample size of 32. The data was collected through qualitative techniques and use of unstructured questionnaire.

4.4.1 Conversation in extension services among agriculture scientists: pre-deal scenario

Our study shows that, in the absence of proper channels to facilitate communication most of the scientists of the KVKs operate in isolation and hardly have any opportunity to gain the information and knowledge about other scientists working in her/his area in another district even at the local level. In their respective KVK the scientists also have sparse networks for knowledge exchange. For example in the one of the studied KVK (located at Dhaura) all the scientists maintained reciprocal relationships with the SMS (Subject Matter Specialist - Agriculture Scientist) of horticulture as he was the administrative head of the particular KVK, whereas in terms of actual information sharing they have hardly any reciprocal relations with other scientists (Figure 4.1). Our study shows a low network density among the KVK Scientists in pre-DEAL scenario. The network density for communicative action in pre-DEAL scenario is 0.1199[9]. In the pre-DEAL scenario SMSs of animal husbandry and home science are most isolated actors in the network space of knowledge exchange, whereas SMSs of agronomy, plant protection (plant pathology), farm management and soil science have a unitary mode of networked conversation. These forms of networked conversation hardly meet the rising need for the information resources of the scientists in the present context of the rapid changes that occur in agricultural technology.

4.4.2 Conversation in extension services among agricultural scientists: post-deal scenario

Studies in network architectures suggest that centralised networks are ineffective modes of interaction for information sharing. In contrast a participatory bottom-up approach allows information sharing and communication more effectively. This is where the DEAL has played a crucial role. DEAL aimed to create many communications through an autopoietic network mode among different SMSs of KVKs by linking each of them to others through a digitally facilitated knowledge architecture. The DEK design of the system places special emphasis on voluntary participation, and as more members access the network the number of ties increases, and these ties are mutual, and voluntary.

[9] The network density has been calculated by proportion of ties in the network relative to the total number possible (sparse versus dense networks). Connection weights are ignored and connections are undirected.

Figure 4.2 shows the network developed among various scientists in a post-DEAL scenario. The network density of post-DEAL scenario is 0.6279. Literature in knowledge management and communities of practice suggests that normally people in a structured community of practice (CoP) come from backgrounds having shared knowledge or a shared belief system. In these kinds of structural arrangements often people learn through the facility that is available through structural resources and positions. In contrast, information and communication build a different kind of network, i.e., a network built upon communications, agency, and duality of structure operating in a continuous mode on reflexive interaction and structural reproduction.

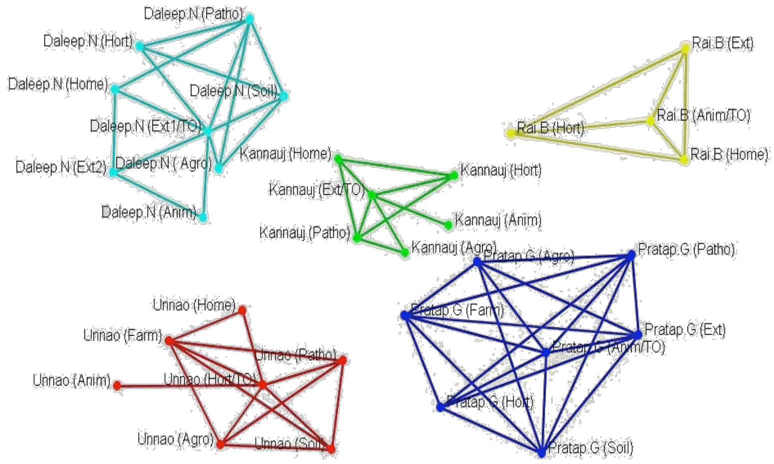

Figure 4.1: Networked conversation in pre-DEAL case

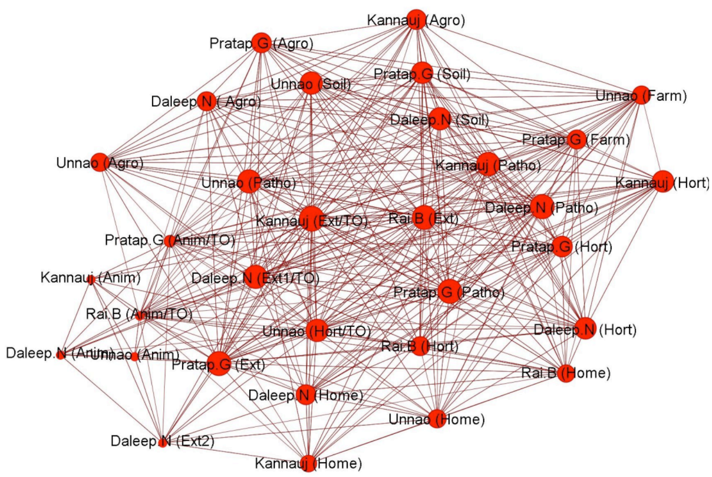

Figure 4.2: Networked conversation in post-DEAL case

Inspired by Luhmann and Giddens we deployed in the DEAL project several new concepts for continuity of conversation and for creating recursive communication loops among the participants at our field stations covering 63 villages and six Agricultural Knowledge Centres in Northern India. It is too early to demonstrate the full impact of our concepts and processes for supporting autopoiesis. The social network analysis for the pre- and post-DEAL scenarios shown in Figures 4.1 and 4.2 however show both intensification of the networks as well as significant rise of transactions between the nodes, while the total number of nodes kept increasing. The question still remains whether this is proof enough for establishing the autopoietic nature of the DEAL system. So in the next section we probe further the systemic properties form the biological and socio-economic perspective.[10]

[10] The material used in this section is based on the paper (Pattanaik and Chatterjee, 2009) published in the *IEEE International Conference on Digital Ecosystems and Technologies* (DEST'09) where it won the best paper award in the category.

4.5 Ecosystemic considerations

In this section we present a number of theoretical and empirical advances in the study of social and natural ecosystems, and draw out a number of hypotheses that can be (and are being) explored to underline the study of digital ecosystems[11]. In doing so, we will find that empirical advances in the study of natural ecosystems is also worth exploring and will assess their relevance to the study of digital and social systems. Although more specific, complementary ecosystem models can be found, e.g. related to standardised (technical) concepts for device description ecosystems (Hanrahan, 2007), or vendor-specific (business) analyses on mobile ecosystems (Strategy Analytics, 2008), we will mainly refer to the ongoing dialogue between social science and computer science in OPAALS that has informed the design models underlying the core DE architecture, as reported in Deliverable D3.6 (Moschoyiannis, Darking, et al, 2008).

In the next section we illustrate the importance of innovation processes in sustaining ecosystems. This draws us to introduce some key concepts in ecological modelling, following the work of Gunderson and Holling (2002). We then outline some of the issues with current digital ecosystems before returning to the modelling of social ecosystems. After that we provide a brief overview of the consensus building around the core digital infrastructure between computer and social scientists in OPAALS. Finally, we conclude with some pointers to a research agenda for the science of digital ecosystems.

4.5.1 Models of Social Ecosystems

A primary goal behind our studies of ecological modelling for digital ecosystems is the avoidance of premature commitments to specific technological solutions or directions; the art of engaging with new communities is to leave your baggage and preconceptions behind. Instead, we will adhere to two guiding assumptions:

- Firstly, our core research should focus on generative and disruptive, rather than ‘sterile’, technologies;
- Secondly, minimising the imposition of centralised control or organisation will enhance the ability of the Digital Economy to empower or transform a given socio-economic context.

The two assumptions are closely related, and could be summarised as a target of transforming the Digital Economy into a complex adaptive system, where institutions emerge and evolve through local interactions and memory. These are, of course, assumptions. Their validity must be tested through both empirical and theoretical studies.

4.5.2 Adaptive Cycles, Resilience and Transformation

The concept of ‘ecosystem’ is increasingly being used as a metaphor in business and systems thinking. In itself, this is a more inclusive view than the more traditional hierarchical, or value-chain models – it provides greater acknowledgement of the importance of a community as a whole in sustaining value creation. However, one can go much further in using the metaphor to drive the development of models that have real value in understanding and facilitating transformation in the Digital Economy.

The adaptive cycle concept emerged from studies of regional development and ecosystem management that were conducted in the 1980s and 90s (Gunderson, Holling and Light, 1995). The concept of a climax community is well understood in natural ecosystems. This corresponds to the K or Conservation phase of the adaptive cycle in Figure 4.3. But established business or stable socio-economic ecosystems also have an analogous K phase in which interventions and controls are typically chosen to maintain or streamline the delivery of the ecosystem’s outputs. At some time, a change in either an internal or an external variable may trigger a transformation to the Ω or release phase (e.g. a forest fire, in a natural system, or the shift from a product oriented to a service-oriented market place in the case of business ecosystems). The system may then respond with reorganisation before moving back through exploitation into a new (and possibly qualitatively different) conservation phase.

[11] The material in this section draws upon the position paper (Krause et al, 2009) published last month in the *IEEE International Conference on Digital Ecosystems and Technologies* (DEST’09) where it won the best paper award.

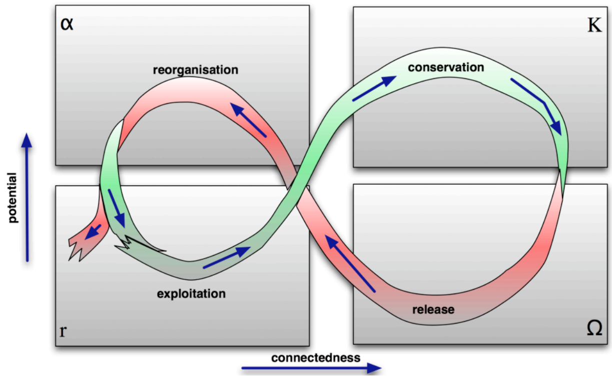

Figure 4.3: The adaptive cycle

The adaptive cycle of Figure 4.3 works well as a metaphor for many social-ecological systems. It also provides a useful framework for posing research questions and structuring simulations/experiments in Digital Ecosystems (Gunderson and Holling, 2002). An important extension of this is that in most systems there is a hierarchy of such cycles (usually working on different time scales). A change in system variables in one level can trigger change in other levels. Typically a large business will hope to work in the "K" sector. But a change in the higher-level business environment can trigger transition to Ω and then α. Note that if the response is not effective, the cycle can exit at "r".

Both natural and social/business ecosystems will demonstrate a degree of resilience to external change or shocks whilst in the K sector. In part a certain level of response diversity in the face of external change can provide this. Contrast the coral reefs of Great Barrier Reef (GBR) to those of the Caribbean. There is much higher species diversity in GBR. This in turn means that the various (trophic) functional groups in GBR have significantly enhanced response diversity compared with the coral reef ecosystem in the Caribbean. Broadly, this is what is currently providing the GBR with greater resilience than the coral reefs of the Caribbean (where there has been an 80% decline in hard corals).

This metaphor of *response diversity* in business ecosystems suggests that SMEs are a major factor in maintaining resilience of the ecosystems in the face of extreme events. The focus on larger shocks is a consequence of the difficulty of modelling complex systems. It is a common modelling strategy to start attempting to capture the larger effects and refining the model later. Thus, our aim is to build resilient ongoing ecosystems and hence we are interested in the response of the ecosystem to extreme events because it is these shocks that can cause irretrievable system dislocations. This hypothesis is not established, but it does raise interesting research questions that can be addressed through simulations and comparative analyses of real-world case-studies. (It is appropriate that this report was written in a time of financial uncertainty where resilience will be tested to the full.)

In general, resilience is a property that emerges from a range of features in any complex system. The mistake is often to use simple interventions to try to control a system in the face of some external pressure or shock, without considering, or even being aware of, all the variables that impact on the stability of the state of a complex ecosystem. Because authors like Foucault, Giddens and Mouffe do not rely on a model-based analytical methodology their theories are not as constrained to start from understanding the effects of shocks and can afford to be more fluid and nuanced. A number of case studies on the resilience of a range of social ecosystems can be found in (Gunderson and Holling, 2002). Some key lessons can be drawn from this:

- Interventions are often planned without taking into account, or even being aware of, one of the key variables of the ecosystem;
- Interventions are planned on individual components of a complex system, without modelling how the system may adapt as a whole to these changes of individual components;
- Ill-conceived interventions can impact on the *resilience* of an ecosystem to withstand extreme events;
- Without carefully modelling the impact of an intervention, we may trigger an unrecoverable transition from one *stable state* to another (for example, the transformation of species rich sawgrass communities to single species stands of cattail, in the Florida Everglades).

In the case of digital ecosystems and, in particular, business ecosystems, we believe SMEs play a critical role in maintaining the response diversity in the face of global change. However, as will be discussed shortly, SMEs are not fully engaged in the Digital Economy, and in many cases are seriously disenfranchised from it. The importance of understanding the dynamics arising from the complexity of ecosystems and "panarchies" of ecosystems is not just in understanding how to maintain a valued ecosystem. It also helps us to understand the variables that impact on our ability to transform an ecosystem into a new, more desirable, state. This has provided a short introduction to a number of key concepts. Before extending this to cover sustainability and the important enhancements of memory and intention that are needed for the study of social ecosystems, we will provide an overview of the current situation with digital ecosystems.

4.5.3 An Inclusive Digital Ecosystem for SMEs

In the EU-27, the percentage of enterprises' total turnover from e-commerce via the internet doubled between 2004 and 2007, passing from 2.1% (2004) to 4.2% (2007) of total turnover (Eurostat, 2007). However, for B2B transactions among SMEs, on average only about 11% of SMEs use software solutions or internet-based services for e-procurement. Moreover, there is a massive gap between the percentage of SMEs placing at least some orders online (53% of total) and those that use special software for this (only 11% of total). SMEs without special software place orders mainly through websites or extranets of suppliers (European Commission, 2007). The result is a lack of digital back-office integration of procurement-related processes among European SMEs.

As discussed in (Dini et al, 2008) a major barrier to the expansion of use of B2B amongst SMEs is that the current standards for web service coordination require a central coordinator. Even where there is a natural hub for the business activities, this can provide a threat to the local autonomy of the participating SMEs – the web service coordinator will have access to business state, business logic and data about traffic that can help in enforcing a level of governance on the participating SMEs, and also inform acquisition policies of the coordinator. A distributed coordination model for long-running business transactions that aims to alleviate such concerns has been proposed in Moschoyiannis et al (2009) and Razavi et al (2007a).

However, these are not the only barriers to adoption of digital innovation amongst SMEs. Our own studies in the Cambridge region indicate more fundamental issues need to be addressed, including: Intense frustration at the lack of interoperability and loss of core business time; an already low ICT take-up. This situation is frustrating a potential expansion of the digital economy that would be of major significance. The focus on networking, collaboration and cooperation continues to develop in modern business processes (Marceau and Dodgson, 2000), and is especially important amongst communities of SMEs. Greater inclusion into a technology-enabled business landscape will enhance their capacity for achieving a form of "competitive co-evolution" (Ordanini, 2001). We believe this model is especially relevant to the information-based industries that are becoming increasingly important in the redevelopment of the UK economy.

The tourism industry provides an example of the strong contrasts in inclusivity of the Digital Economy (Braun, 2006). Increasingly, consumers rely on the Internet to search for information, and book their vacation. Yet, while many of the more satisfying (and socio-ecologically sensitive) vacation experiences can be found and booked through 'micro-tourism' websites, these are easily eclipsed by the mega-tourism sites such as *Travelocity* and *Expedia*. The barriers to adoption are not just technological. Evans et al (2001) found that:

- Micro and small tourism enterprises don't identify themselves with the mainstream tourism industry
- The lifestyle choice of owner-operators often militates against their take-up of ICT

In addition, tourism SMEs tend to rely in intermediaries for their marketing and so have limited bargaining power in the distribution channel (Buhalis, 1999). Our own work with the UK Technology Strategy Board and Regional Development Agencies indicates that these problems arise repeatedly across many SME sectors.

Further, the analysis in Deliverable D3.6 (Moschoyiannis, Darking, et al, 2008) indicates that the behaviour of SMEs from an information systems and management perspective is driven by external uncertainty and independence. On the one hand, small firms aim to remain independent and autonomous, and are prepared to avoid business activities which put their independence and autonomy at risk (Drakopolou-Dodd et al, 2002). On the other hand, small firms are marked by external uncertainty that derives from their low capability to control the external socio-economic environment and conditions, being thus more likely to evolve and change over time than larger organisations (Storey, 1994).

The key lesson we want to draw from the above is that the development of digital ecosystems needs to take into account the social perspectives of its members. However, mathematical or numerical models of social interactions are not very effective at capturing properties that social science considers fundamental to social systems, such as we have discussed in previous chapters. Thus, we now return to ecological modelling and expand this to discuss inclusion of the socio-economic context in the models, but with the understanding that such models can only capture a small part of the social dimensions of ecosystems, which remains an interesting long-term research question. We then discuss how the more theoretical social aspects of interest in digital ecosystem research have been considered in the design models that underpin the core digital ecosystems architecture in OPAALS.

4.5.4 Response and Sustainability

So far, we have emphasised the importance of *response diversity* in providing a degree of resilience to shocks on an ecosystem. However, this may not be sufficient to guarantee recovery of an ecosystem. In addition, it is not only shocks that may trigger the transition of an ecosystem from the K (conservation) phase to the Ω (release) phase of the adaptive cycle, and its subsequent reorganisation into a qualitatively different regime. There is good empirical evidence from natural ecosystems that in certain circumstances they can respond catastrophically to a gradual increase in stress.

Catastrophic responses. We will summarise the discussion from Scheffer et al. (2002) in this sub-section. For simplicity we will only consider one ecosystem state variable, and one impacting state variable. A common assumption in ecosystem management is that some increase in stress on that ecosystem will lead to a steady and gradual change in its state (Figure 4.4, below).

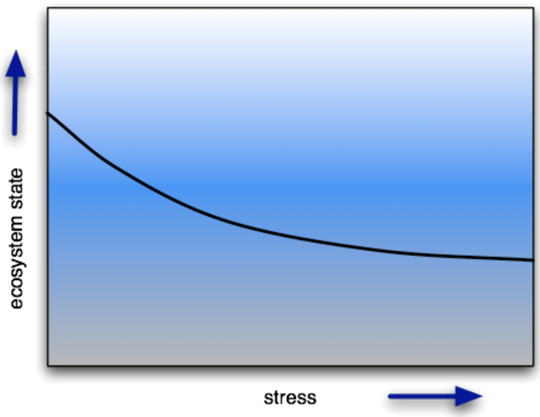

Figure 4.4: Naive model of ecosystem response to stress

This supports a comfortable feeling that if the ecosystem state deteriorates below an acceptable level for certain stakeholders, then it may be recovered simply by reducing the stress. That is, a K to Ω transition may be reversible. Unfortunately, as we will describe in a concrete example shortly, a given ecosystem may support (at least) two stable equilibrium states over a range of environmental conditions. In such a scenario, the ecosystem may be relatively inert to change in stress over a certain range of conditions, but then respond with a catastrophic switch to a new stable state once the environmental stress exceeds a certain threshold (point F2 in Figure 4.5).

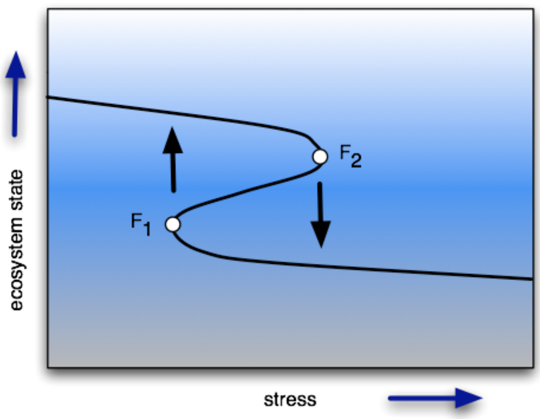

Figure 4.5: Stress may induce catastrophic change

Two key issues arise. Firstly, given the relatively benign initial response of the ecosystem to the environmental stress, the catastrophic switch to a new stable state will typically be hard to predict and prepare for. Secondly, given the hysteresis effect of such a response curve, a very significant reduction in stress level will be needed before the ecosystem will transition back to the upper branch (point F1 in Figure 4.5). Indeed, it can happen that the point F1 is to the left of the origin, and hence not reachable through a simple reduction in the stress factor that led to the transition to the lower branch.

It is worth including a concrete example to keep this chapter self-contained. Both clear lakes and arid ecosystems fit well to the above model, but given the greater experience of linking them into socio-economic systems, we will use the example of clear lakes following Brock et al. (2002). Fertiliser run-off from agricultural communities, and wastewater from other human activities can impact clear shallow lakes. The resulting increase in nutrients ("stress") stimulates the growth of phytoplankton. The resulting green turbidity reduces light intensity and hence impacts the characteristically lush plant growth on the bottom of the lake. This impacts on the small animals that feed amongst this vegetation. The fish species that feed on such animals, attach eggs to such plants or use submerged plants for shelter will then also decline. Finally, in response to the reduction in fish species, the number of birds visiting the lake will decline.

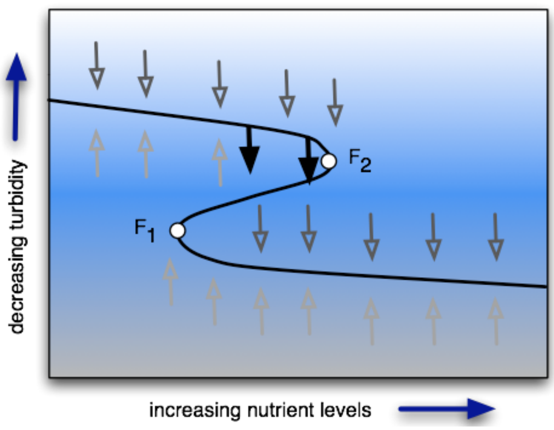

Figure 4.6: Resilience is minimal near the tipping points F1 and F2

A disturbance, or shock, to the ecosystem can be represented by a vertical displacement from the equilibrium line. Such a disturbance in this case might be a sudden increase in nutrient levels due to prolonged heavy rain, or a significant fish kill. Once the disturbance ceases, the system will return to equilibrium (the grey arrows). But note that if a large disturbance or shock occurs (represented by the heavy black arrows) near to the point F2, it may tip the system into the second highly turbid stable state.

Resilience and Sustainability. It is still hard to gain a consensus on the semantics of sustainability as a concept. During the lead up to the Local Agenda 21 actions at the end of the last century, the Brundtland Commission defined sustainable development as:

> development that meets the needs of present generations without compromising the ability of future generations to meet their needs (World Commission on Environment and Development, 1987).

This is worthy, but a little hard to operationalise; does it mean that we should wind down oil consumption in case a future generation has a greater need for it, for example?

An alternative approach is to consider the sustainability of a social ecosystem in terms of its capacity to absorb shocks and chronic stress (Holling *et al*, 1995). The concepts of *resilience* and the *adaptive* cycle then become important in guiding studies to aid the effective monitoring and management of complex (socio-economic, digital and natural) ecosystems. Provided we can identify all the key variables in an ecosystem, we may be able to combine theoretical and empirical analyses to develop a model of its response to change. As we have seen in the previous section, such models may need to be non-linear or even chaotic (Brock *et al*, 2002). Clearly, we again emphasise that we are talking here about variables that are amenable to quantitative modelling, and therefore we necessarily overlook important aspects of social dynamics that can only be analysed and characterised through complementary qualitative methods. Nonetheless, the modelling approach can still give us useful information of a more 'structural' nature.

The adaptive cycle reminds us that *sustainability* should not be equated with *stasis*. A natural ecosystem may have a need to periodically cycle through instances of the adaptive cycle in order to avoid moving into a situation where a small disturbance could trigger a dramatic or catastrophic switch into an alternative stable state. A well-known example of this is the impact of fire control in temperate forests. Small scale, local, fires (Ω, release, phase) clear forest debris and lead to new growth, regeneration and gradual transformation back to a climax vegetation ($\alpha \rightarrow r \rightarrow K$). Attempts to control this natural cycle lead to a widespread and deep accumulation of forest debris. The potential for a catastrophic forest fire then builds up leading to at best a release phase that is hard, costly and extremely risky for humans to control, and at worst opens the risk of transformation into a new stable state (perhaps regeneration is dominated by a non-native water-greedy tree species, that locks out recovery by the previous vegetation).
Things become more complex (and more relevant to digital ecosystems) when we include human social and economic interests into the ecosystem models. At this point we will quite often (perhaps usually) move away from closed cycles around the adaptive figure of eight. The release phase may be triggered by a factor internal ("revolution") or external ("remember") to the system. The ecosystem then needs (as humans are now involved, aspects of intention become relevant) to reorganise into a different state in order to succeed in progressing through the *exploitation* phase into a new (quasi-stable) *conservation* phase.

Gunderson and Holling in (Gunderson and Holling, 2002) use the example of the Florida Everglades to demonstrate the institutional response to a series of ecological crises over the last century. Essentially the tensions there are between water management to support increasing economic development in a natural ecosystem where widespread flooding (release phase) was an important part of the latter's adaptive cycle. To summarise briefly, we list here the institutions that were generated, together with the crisis that triggered the reconfiguration:

- 1903, Everglades Drainage District (Flood)
- 1947, Central and Southern Florida Flood Control District (Flood)
- 1971, South Florida Water Management District (Drought)
- 1983, Everglades Coalition (perception of switch to new ecological state and fear of pollution through high rainfall)
- 1989, Everglades National Park Protection and Expansion Act (Costly water quality lawsuit)

A full description of the evolution of the Everglades social ecosystem can be found in (Walker, 2006). The important point here is that the Florida Everglades social ecosystem went through a sequence of 'release' and reorganisation phases as memories of the consequences of external shocks triggered the emergence of

new institutions. These can be thought of as representative of new states in the history (ontogeny) of a complex adaptive socio-economic system. Collective memory in the system (hopefully) prevents reversion to an earlier, less resilient, state. How the system may be able to reorganised could be described or explained in different ways depending on whether one adopts the democratic process perspectives of Chapter 2, or a complexity science-oriented notion of emergent 'collective intention', or some other theory of socio-economic action. Regardless of the explanatory theory of choice, the desired outcome is for the system to reorganise following release phases into states that are (hopefully) more resilient to external and internal tensions. The development of well-informed models of socio-economic systems, or qualitative theories of their behaviour and of the behaviour of the individuals that populate them, is absolutely essential for continuing to guide the reorganisation of complex social ecosystems following a release phase.

4.6 Non-linear mathematics for an economics of complexity

Having spent some words on ecosystem behaviour, it is pertinent in the development of a theory of digital ecosystems to address also the mathematics of non-linear economics. The development of an interdisciplinary theory combining economics with complexity science presents very challenging theoretical problems. Some might want to question why one would want to even try, on the basis that we can inform policy through other means that do not rely so heavily on physics or biology metaphors or on mathematical models. We are starting from the assumption that it seems worthwhile to take a closer look at this question, in the hope that new analytical insights might result from the effort. We only mean to propose an initial outline of a research programme that will surely take many years to develop, to give an idea how and why such an approach is relevant to digital ecosystems.

4.6.1 Scope

Our interest in heterodox economics creates an obstacle to the development of a mathematical extension to general equilibrium theory that can do justice to complexity science: this is because the objectivist epistemology of mathematics and the interpretation of economic behaviour such as the emergence of economic institutions through, for example, Giddens's structuration are very close to being mutually exclusive. In other words, we are caught in two opposite positions: if we enrich and generalise equilibrium models with non-linear dynamical systems and far-from-equilibrium models, we lose the social constructivist aspects; if we enrich and generalise equilibrium models with intersubjective or social constructivist understandings of reality formation and institutionalisation processes, we lose the ability to quantify and we give up any hope of predicting formalised economic behaviour. Of course empirical 'falsification' and quantification remain essential, but our ability to develop predictive models based on empirical data remains limited. Empirically grounded analysis can still be very effective at informing policy – but it is not complexity science.

Before we venture into the development of a mathematical argument we need one more disclaimer, namely that mathematics, by itself, can *never* be sufficient to characterise a socio-economic system or to predict its behaviour in a way that could ever be regarded as 'complete'. And yet it is quite clear that some patterns of behaviour are present in different systems and contexts, and that some features or characteristics of different systems or processes appear to be similar. To a mathematician this simple observation indicates that the problem is amenable to some level of mathematical description. Thus we are open to the possibility that, rather than a unified model of quantitative and qualitative behaviour, our efforts might lead to a 'composite model' which produces separate but mutually compatible information that is relevant to these two different epistemological viewpoints.

Another dimension that we could add to the epistemological space defined in Chapter 3 is *abstraction level*: at high-abstraction, low-resolution levels, where the role of the individual is vanishingly small, mathematical models might have a bigger chance of telling us something useful about the system's behaviour. By contrast, as we add more concrete details about the context, mathematical models become progressively less effective and we need to resort increasingly to alternative subjectivist epistemologies to analyse systems and inform policy. So we see that our inter-epistemological framework might be not only

composite but also hierarchical. The gross, structural features of the system may be well-captured by a mathematical model, but as we move away from aggregate variables we will need to forsake mathematics, switch epistemologies, and abandon even the very concept of 'model'. The situation at the other end can be succinctly summarised by the idiom "*You had to be there*". Furthermore, the correlation between level of abstraction and choice of epistemology suggests that these two dimensions may actually not be independent but appear to be correlated.

4.6.2 Models and metaphors

We see two broad ways in which economics and complexity science can be combined. In the first way, quantitative and mathematical economics is enriched or extended to take into account the *mathematics* of complexity science. Our interest is in clarifying the role mathematics can play in enriching existing mathematical *models* in economics by their extension in the direction of complexity science. We mean the term 'complexity science' in the limited sense of the integration of non-equilibrium statistical mechanics with non-linear dynamical systems that can be applied, for example, to the study of open out-of-equilibrium systems such as the biological cell. In the second way, complexity science *concepts* are absorbed by heterdox economics in such a way that, wittingly or unwittingly, a predominantly subjectivist epistemology is relied upon. In fact, even if plenty of quantitative data are relied upon in the analytical work, the result does not have to be consistent with a general mathematical model. This is a case where economics uses physics and mathematics concepts as *metaphors* to construct new and different understandings of problems and systems that may end up having little to do with the biological or physical phenomena their conceptualisation was inspired by.

4.6.3 A question of scale

In the search of mathematical frameworks relevant to economics, three 'big ones' stand out above the rest: statistical methods, general equilibrium theory, and game theory. In this chapter we focus only on the first two. The 'law of large numbers' leads us to make the easily refutable hypothesis that *scale* could matter to our discussion, and could help us begin to pose this problem.

The easily refutable hypothesis is that, as the scale of economic systems increases, the equilibrium assumption becomes more justified and leads to more accurate predictions by models based on this assumption. This hypothesis is motivated by the spectacular success achieved by equilibrium statistical mechanics in modelling the thermodynamic properties of 'large' physical systems that are, in fact, in thermodynamic equilibrium. 'Large' in this context refers to a number of particles or elements on the order of Avogadro's number (10^{23}), such as the number of molecules in a litre of air at room temperature. This success is a consequence of the fact that the Central Limit Theorem, which says that the frequency distribution around the mean of a random variable converges to a (sharply peaked) Gaussian with increasing sample size, does indeed apply for large systems in equilibrium. This simple fact explains the overwhelming use of statistics in macroeconomics and quantitative methods in sociology, psychology, market analysis, etc. In other words, the 'law of large numbers' is assumed to hold more the larger the system being analysed is. However, unlike for physical systems whose conditions can be closely controlled, there is no guarantee that a large socio-economic system will be anywhere close to 'equilibrium', however we wish to define this notion. This is why the hypothesis is easily refutable.

Be that as it may, even if we can't prove that large socio-economic systems are in equilibrium, it is certainly true that as the number of consumers being analysed decreases from millions to a dozen, the importance of the individuality of each consumer becomes more important, as do their social interactions. As the size of socio-economic systems decreases, models that treat persons on par with air molecules become increasingly less able to capture the behaviour or the motivation of the economic agents. Here we find that the hermeneutic, subjectivist, or intersubjective epistemological traditions are much more effective at explaining what is happening. Qualitative empirical research methods become more important than quantitative metrics or indicators. Suddenly, the mathematics appears quite pointless.

Now let's retrace the same steps from large to small, but this time following a physical system. Large chemical systems in equilibrium satisfy the assumptions of the Central Limit Theorem, as we said. If we try to apply to apply statistical methods to the analysis of much smaller systems such as the biological cell

in order to derive its macroscopic properties, however, the predictions fail. This is because not only is the cell a much smaller system ($\sim 10^7$ rather than $\sim 10^{23}$ elements), but it is also not at all in equilibrium. The physical reasons for this are extremely interesting because the distance of the cell from equilibrium is precisely what renders it 'self-organising' (Dini and Berdou, 2004). In other words, the engine of spontaneous behaviour, or the 'self' part of self-organisation, is the 'fall' towards equilibrium. For such spontaneous behaviour to be also 'organising', it needs to be constrained appropriately, something biological systems are able to do very well. Finally, for the system to *remain* self-organising, it needs to be kept at a constant 'distance' from equilibrium, even while continuously falling towards it, by a constant energy influx, i.e. food. From this, we conclude that for biological systems Equilibrium = Death. Thus, in contrast to large chemical systems, small biochemical systems require a different mathematical approach to deal with their considerably greater complexity and time-dependent behaviour.

The mathematics of cellular biology is currently a field of intense research. Of the many possible analytical and numerical approaches currently being pursued we find it very useful to focus on dynamical systems theory, and in particular on the rich algebraic approaches that can be found within this branch of mathematical physics, which is becoming increasingly integrated with computer science. There are two reasons for this. The first reason is that dynamical system theory offers the possibility to develop a modelling framework that is scale-invariant. In other words, in those cases where even very large socio-economic systems are far equilibrium (which some economists consider to be the overwhelming majority) a dynamical systems approach offers the possibility to capture the 'structural' mathematical properties, in the sense we defined above, of the system's time-dependent behaviour by operating on suitable aggregate variables. The effectiveness of such an approach is not to be taken for granted and depends not only on the choice of variables but on some of the analytical concepts to be discussed further, below. The second reason is that dynamical systems theory gives us a convenient link to general equilibrium theory. Before we address that, the following sub-section provides some historical context for this discussion.

4.6.4 Historical view of the generalisation and incompleteness of existing equilibrium theory

Economics is a discipline that deals with production, distribution and the consumption of wealth. The main concept is *value*, since it attempts to determine what is valuable at a given time by studying the relative exchange values of goods and services. Consequently, economics is probably the most normative of all social sciences, since it is value-dependent. This is the main reason why all models and theories are based on a value system. Contemporary economists, probably just trying to give economics more scientific rigour to the discipline, have avoided the issue of unstated values. Values that appear in current economic models are those that can be quantified by assigning monetary values. There is disagreement about the interpretation of this practice. To many (but not all) non-economists, this practice excludes qualitative distinctions related to the social, psychological and ecological dimensions of economic activities, while to many (but not all) economists the non-monetary values are embodied in the quantifiable values.

Modern economics is about three hundred years old. Along with the mercantilists, John Locke was one of the founders of modern economics, being strongly influenced by Descartes and Newton. One of his most innovative theories had to do with prices, which he said were determined objectively, by demand and supply. This cornerstone of economics stands today in most of economic analyses. The law of supply and demand fitted with the mathematics of Newton and Leibniz because of its links with differential calculus and continuous variations. This notion set the first basis of many efforts to turn economics into an exact mathematical science. The French Physiocrats were the first to call themselves "objectively" scientific through an "ecological" view that claimed that agriculture and land were the only producers of real wealth. Their idea of the Natural Law then evolved to the doctrine of *laissez faire* that is another keystone of economics.

The thought of Adam Smith came together with the industrial revolution and with the period of the "classical political economy". Smith adopted the concept of laissez faire through his metaphor of the Invisible Hand, and believed in the labour theory of value, but also on the fact that prices were determined in "free" markets by the effects of supply and demand. His theory is based on Newtonian notions of equilibrium, which creates difficulties of application to social phenomena. Smith believed that the

balancing mechanisms of the market would be almost instantaneous and, thus, small producers and small consumers would meet in the marketplace with equal power and information. This idealistic picture underlies the “competitive model” used by many economists today. The three main assumptions are: perfect and free information; all market players are small and have no influence on prices; and complete mobility of workers, resources and machinery. Most of these conditions are nevertheless violated in real markets.

At the beginning of the nineteenth century, there were continuous attempts to turn economics into a form of science. David Ricardo introduced the concept of an “economic model” defined as “*a logical system of postulates and laws, involving a limited number of variables that could be used to describe and predict economic phenomena*” (Capra, 1988). Classical economists supported the existence of social class structures and used the argument of “laws of nature” to counter all attempts of social improvement. Welfare economists built over their theory of optimality through elaborated mathematical schemes; and Utopians introduced humanitarian principles based on a cooperative-based, ecologically harmonious social order. Mathematical economics is devoted to study the market mechanisms with the help of curves of supply and demand expressed as functions of prices and based on nowadays far-from-realistic assumptions of economic behaviour.

Stuart Mill, a classical economic reformer, came to the radical conclusion that distribution was not an economic but a political process, narrowing the political economy to pure economics, to be then called “neoclassical”, focussing on economic processes and excluding social and environmental variables. After Mill, economics was split between neoclassical/”scientific” based on mathematical approaches; and the “art” based on social philosophy. Karl Marx, in his “Critique of Political Economy” used the labour theory of value to talk about justice and developed new concepts to counter the reductionist logic of neoclassical economists. He had a systems view of the process of production. He emphasized the importance of nature in the social and economic fabrics, seeing society as an organic whole in which ideology and technology were equally important.

After the Great Depression, John Maynard Keynes made economics once again political viewing economic theory as an instrument of policy. He demonstrated that economic equilibrium states were “special cases” rather than the real world. To justify government interventions, Keynes shifted the focus to the macrolevel using variables such as national income, total consumption total investment, total volume of employment, etc. Several economists applied practices as printing money, varying interest rates, cutting and increasing taxes, etc., although these methods ignore the details in the structure of the economy and the qualitative nature of its problems. A modern version of neoclassical economics introduced more sophisticated mathematical techniques but based on classical notions. Post-Keynesians reject the free-market model and the concept of the Invisible Hand; but they still use highly aggregated data derived from microanalyses; and do not have a view on the ecological dimension of economic problems.

Quantitative models based on the theories and models briefly mentioned above only describe fragments of economic reality, and they are usually based on the Cartesian paradigm and thus unable to describe interrelated and dynamic global economic systems. The non-inclusion of social issues in current economic theory is related to the inability of economists to adopt an ecological perspective. Equilibrium models based on a balanced free market and classical assumptions are no longer valid and appropriate to map economic activities within an interrelated world.

In the discussion of the sections above on the generalisation of general equilibrium theory and digital ecosystems theory, it is evident that a revision of concepts and theories including a non-linear extension of mathematics and sociology is required if there is the interest of creating a useful approach that defines scientifically economic reality. This theoretical framework should be based on a systems approach that includes biology, sociology, political philosophy and economics into a broad ecological framework. This should also include human attitudes and values into a matrix that defines a truly global ecosystem.

4.6.5 A generalisation of general equilibrium theory

We regard general equilibrium theory as insufficient to account for the motivation and behaviour of economic agents. Consequently, the extremely high level of success that this theory has enjoyed over the past 150 years gives us pause. Perhaps its success could be ascribed to the role that the concept of equilibrium has played in the mathematical ontology and epistemology of economics. We posit that as a mathematical model that grew out of physics general equilibrium theory could only rely on a single globally organising concept analogous to the principles upon which physics relies: equilibrium. The role of this concept in providing a solid anchor to the mathematical model has so far outweighed the inefficacy of the model itself. Unlike general equilibrium theory, game theory did not come from physics, it originated within economics as a mathematical model of the Invisible Hand. Although game theory also has its problems and limitations, it successfully embodies another globally organising principle of seductive simplicity, namely that each economic agent strives to maximise its utility.

If we compare the mathematical approach of general equilibrium theory to its analogue in the physical sciences, we notice that in the latter we are able to rely on several more global principles, such as the conservation of energy, mass, and momentum. Furthermore, and more importantly, in physics we can also rely on a global minimisation principle called Hamilton's Principle whose importance resides in the fact that the majority of physical laws (Newton's 2nd Law, Schrödinger's equation, etc) can be derived from it by a simple application of the calculus of variations. The absence of a similar global principle in economics, no matter how reductionist an economics one is willing to build, has undercut the ability of mathematical models in economics to take advantage of some of the extremely powerful results available from mathematical physics. Therefore, it is perhaps not surprising that so much emphasis has been placed on the mathematical formalisation of the concept of equilibrium – to make up for the 'void'.

Proceeding with the analogy with physics, the prices that clear the market in general equilibrium theory are analogous to the steady-state values of the dynamical variables of a physical system whose time evolution is governed by a set of coupled (and generally non-linear) differential equations. However, whereas such equations in physics are usually derivable from reliably immutable and globally true physical laws, in economics we only have a set of supply and demand curves that are at best built from empirical data and that are in any case far from universal but are very much context-dependent. Furthermore, since such curves are the analogues of the solutions of the differential equations of the physical problem, but the corresponding differential equations are unknown in economics, we are in the paradoxical situation of having to guess the solution to a problem that we cannot even pose.

The generalisation of general equilibrium theory towards the mathematics of complexity, therefore, must address the lack of governing economics equations of comparable richness to what physics has to offer. The methodology by which such equations were derived in various fields of physics (long before the existence of Hamilton's principle was even suspected) does not seem to be immediately transferable to economics because the fundamental units or 'differential elements' in economics are either too heterogeneous or, worse, they are individual *people*!

And yet in the (generally) orderly behaviour of economic systems we recognise significant similarities to the self-organising behaviour of biological systems. Therefore, we infer that some degree of mathematical equivalence must apply between these two kinds of systems, and that a suitable choice of variables in economics might help us derive the corresponding governing equations. At the same time, advances in our understanding of the dynamics of self-organising complex systems such as the cell could give us clues about analogous relationships between the corresponding economic variables. In other words, at a sufficiently high level of abstraction we are postulating that biochemical systems and economic systems may be isomorphic. This is what we are planning to research over the next few years in our research programme on the mathematics of an economics of complexity.

4.7 Conclusion

Our experimentation with DEAL project shows that in a post-DEAL scenario there is a continuous dialogue among scientists of the KVKs both at horizontal and vertical level. This has been done by creating a platform for different KVKs to share their extension experiences with each other through multiple media facilitated by ICT tools and technologies. Autopoiesis happens through communication among the nodes when the transfer of relevant knowledge occurs among them. Learning begets more learning; people not only learn what others know, but also learn the best ways to make others share what they know. The DEAL experience shows that organic formation and autopoiesis in DE happens when people are given access to tools for building communication based relationships just like biological bed. DEAL as a digital ecosystem for knowledge, demonstrates the emergent behaviors that can make and DE platform self organising and self sustaining. Most of the content at the DEAL portal has been created outside of any structured mandate and through voluntary participation. The participating community has developed it, because; there was an opportunity and need.

One of the most fruitful out come of the DEAL experiment was the "cross-pollination" effect of different internal cultures brought together electronically[12] People whose physical paths might have never intersected were able to interface and integrate in a new knowledge nexus. These different groups of people conversed with each other under a variety of contexts; as cohorts, subject experts, interest groups, domain stakeholders, practitioners and observers of the world. Knowledge sharers at the DEAL portal conversed both through the technology and as well as about the technology because they recognised together how improvements in interface design and content delivery can help them discover, exchange, and use information and communicate more effectively. This takes us to our other framework-Structuration discussed in this paper earlier. The process of agency construction depends on agents capabilities to actualise agential coefficient and transform structural properties (here the need for ICT tools to communicate effectively) and in turn be transformed by them. Without agency and existence of duality of structure it is difficult to imagine autopoiesis in a social system such as DE and without autopiesis it is hardly believable that such system can be self organising and self-sustaining.

In the next chapter we provide a brief overview of the synergy between social and computer scientists in OPAALS and how the design models underlying digital ecosystems have been put into dialogue with the main issues of relevance from a social science viewpoint. We present a brief overview of how we have attempted to operationalise some of the key concepts found in social and ecological ecosystems into the design models that underpin the core DE architecture in OPAALS.

[12] Similar observations of cross pollination effect for knowledge sharing cultures have been suggested by Figallo and Rhine (2002).

5. INTEGRATING DIGITAL AND SOCIAL SYSTEMS

5.1 Introduction

Introduction of Information and Communication Technologies (ICTs) has an important impact on our perception of ecosystems with human agents. Clearly, the very concept digital ecosystem suggests that some activities and interactions of the system take place in a 'computerised' form.

An effective way to integrate our understanding of digital and social systems is to draw an analogy between Giddens's structuration and technology development. As we have discussed in Chapter 4, the emergence of institutions through the embedding of customs or norms in an organisation happens through various memory mechanisms, such as the minds of the people involved, the discourse they share, and the guidelines, rules, and norms they make explicit in writing. The presence of this body of norms and rules in the minds of many individuals and on external media ensures its persistence over time, leading to the acquisition of its own identity as an 'institution' in the social consciousness. The actions and behaviour of individuals become constrained to varying degrees by institutions, even if the same institutions are continually being renewed and modified, again to varying degrees, through the very same actions of the individuals themselves.

Technology, and software in particular, can be seen as the formalisation of a similar process of institutionalisation, but over a mixture of hardware and software infrastructure, electronic media, applications, formal languages, and explicit technical knowledge codified through non-electronic media. So whereas the faster communications ICTs enable can catalyse social processes and interactions, their greater complexity and strict internal interdependences lead to a greater level of inertia than is observed with social institutions, which we experience as the problem of legacy software. Taking a cue from biological evolution, a digital ecosystem could be defined, from the point of view of the digital technology, as an environment in which the recombination of the software's elemental components enables a better balance between legacy and innovation.

5.2 Social spaces of formal systems

Thus, for the purposes of this chapter, we may analyse ICT with respect to the following *simplified technology layer model*:

1- 'Technical' theoretical and engineering understanding
2- Technology
3- Infrastructure
4- Applications

In brief, technical theories and engineering understanding dictate what can be done and at what cost. Technology represents the repertoire of reasonably well-processed modules to be utilised outside the laboratory environment. The division between infrastructure and applications typically emerges as a rational attempt at optimising the costs of applying technology – the drawback, of course, is the rise of the legacy systems. Finally, as a whole – since we are talking about a socio-technical and economic system – objectives, values, and shared understanding of people and human organisations have an active role at every level.

The above simplified breakdown of ICT is needed in ecosystemic thinking for two reasons. First, it defines the *technological degree of freedom* of a particular ecosystemic model in the technological sense: for instance, can (or should) entities of a particular digital ecosystem develop new technology, improve the infrastructure, create new applications, or 'only' choose from a list of existing applications? Second, acknowledging this breakdown and the process that has led to it may help scoping, explaining, or even

predicting what kind of *socio-technological evolution* the entities of a particular digital ecosystem might demonstrate.

Note that similar layered abstractions can be established in order to understand specific aspects of the system, e.g. the evolution of the formal knowledge (sub)component in a digital ecosystem (Nykänen, 2009). Refining the simplified technology layer model provides digital ecosystems theories with different kinds of *technology models with different levels of granularity*.

New needs, ideas, or innovations do not always immediately yield new applications. Infrastructure is never optimal either, at least from a particular application's point of view. This is because on a large scale ICT itself evolves as a cultural-economic phenomenon: human beings do not inherit the knowledge of their forefathers in terms of biology, but in terms of learning (of various forms). Also, existing infrastructure and applications carry a significant investment. In ICT development, this has traditionally led to layered architecture models and modularisation in software engineering (see, e.g. Sommerville (2004)). In fact, because of the limitations of human cognition and the existing investments, modularisation may be seen as something fundamental to technical and scientific advancement. The famous quote from Alfred North Whitehead (1861-1947) captures this stance particularly well:

> Civilization advances by extending the number of important operations which we can perform without thinking of them

Thus, in order to escape re-inventing the wheel when it is not needed, practitioners of ICT typically emphasise interface design in applications.

Let us then briefly consider social systems that deal with knowledge through a perspective that is not informed by structuration theory and whose touchpoints with structuration we will continue to investigate during the final year of the project. The famous SECI model (Socialisation, Externalisation, Internalisation, and Combination) by Nonaka & Takeuchi (1995) introduced the notion of knowledge as an active company asset or artefact to the general public. Later strengthened with the notion of Ba (originating, interacting, cyber, and exercising) as a place for dynamic knowledge conversion and emerging relationships, the SECI model emphasises the social and the organisational aspects of knowledge management. When refined with the perspectives of an individual (I), group (G), and organisation (O), we may try to understand the dimensions of the marriage of ICT systems and social systems in digital ecosystems research (see Figure 5.1. below).

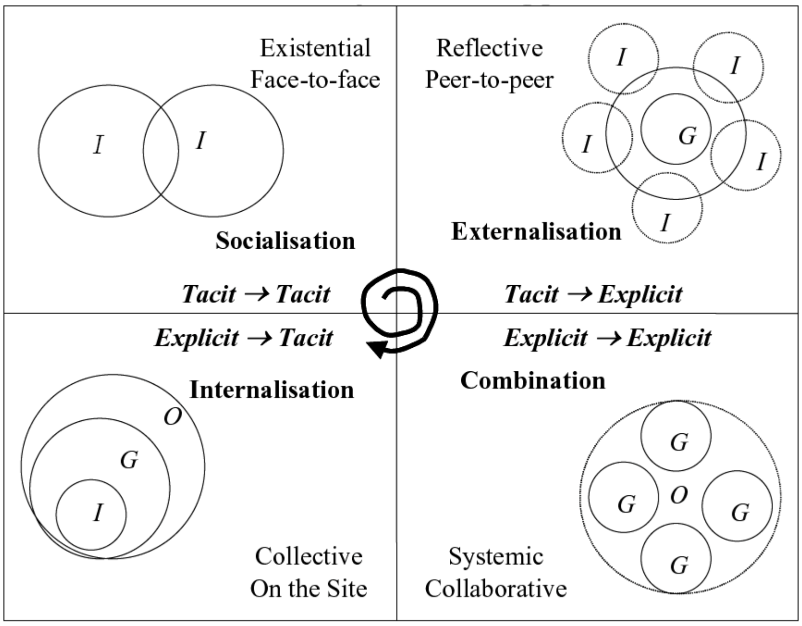

Figure 5.1: Key Elements of the SECI model (Rice & Rice, 2005)

If we accept that computers can directly represent and manipulate only externalised knowledge (e.g. digital/digitalised information), it is clear that computer technology mainly focuses on the process of Combination (e.g. integrating, processing, and displaying data in interaction with the users). However, indirectly, technology may also play an important role in other activities, including Socialisation. This is because ICT may provide, for example, a videoconferencing connection between (groups of) people.

Further, once ICT-supported activities take place, they may produce a trail of externalised process data (e.g. records of meetings) that is highly useful for the individuals, groups, or organisations. Thus, even if the actual content (e.g. paper documents, conversations, gestures, innuendos, etc., not to mention the pragmatics of the activities) of a human meeting might strictly speaking be beyond the Representation and Reasoning System (RRS) of a particular application, the formal container of the meeting (e.g. organisational information, minutes, formal roles of the participants, etc.) might not. As more refined applications for recording human interaction become available, the representation capabilities of the computerised application may approach (or in certain aspects even surpass!) the capabilities of an individual human agent. (As an example, consider recognising vocabulary change within a large organisation over a time-span of 20 years.)

This line of thinking introduces the measure of *ICT pervasiveness* in the digital ecosystem. Given a reference set of ICT applications, an organisation that uses ICT for only, for example, office records management is different from an organisation that uses ICT also for direct group interactions. Note that *several subcategories of ICT pervasiveness* may be identified depending on the research question, including (internal/internal) communication and coordination, knowledge management, business interactions, etc.

Also, the practice and the needs of social systems have an impact on ICT technology development, and vice versa. This seemingly natural observation points to an important relationship between ICT systems and social systems: a digital ecosystem that is supposed to model a complex social system must include a certain *technological baseline* that comes to the simplified technology layer model, otherwise some entities cannot be captured. For example, a digital ecosystem of application end-users differs from application developers. Further, if infrastructure providers are included, the digital ecosystem may need to extend the technological degree of freedom with the level of infrastructures, etc.

5.3 Ontological requirements

Let us consider the ontological framework for digital ecosystem in the ICT context. In brief, we may perceive the ontological framework in two complementary ways: As 1) requirements (i.e. the technological baseline), or as 2) a set of viewpoints to the ICT (e.g. explaining ICT in terms of a digital ecosystem theory).

First, from the requirements point of view, the following observations can be made:

- Knowledge discourse:
  - Baseline requirement: Information management system(s) must provide versioning of data (otherwise archaeology of knowledge cannot take place)
  - ICT pervasiveness requirement: ICT pervasiveness should be high enough to include also informal communications (otherwise significant knowledge flows may not be captured)
- Represent knowledge as data:
  - Baseline requirement: Representations of data must encode also semantics sufficiently (otherwise knowledge automation cannot take place)
- Power:
  - ICT pervasiveness requirement: Social networks including power relations should be represented in an externalised fashion (otherwise, e.g., delegation, authorisation, etc. take place outside the ICT processes)
- Democratic Process:
  - Baseline requirement: Symmetrical interactions without a keystone entity must be supported, at least within certain classes of agents (otherwise groups of agents cannot appear as equals in terms of the ICT aspect)

- Non-linearity:
  - Baseline requirement (in progress): organisationally closed architecture, multifunctional components, integration with evolutionary architecture
  - ICT pervasiveness requirement (in progress): universal interaction model, higher-level specification language with operational semantics, algorithms self-organising around static and dynamic symmetries

This simple analysis reveals that if the technological baseline and level ICT of pervasiveness are not 'rich enough' in a particular system or model of it, certain important aspects of the (full) digital ecosystem theory takes place outside the realm of the ICT aspect of the DE theory. In turn, this observation points out the importance of an **appropriate selection of applicable research methods** in digital ecosystems research. For instance, if pivotal social or business interactions that take place in a way that produces an explicit trace of data within the ICT aspect of the ecosystem, such processes may (easily) be subject to several quantitative research methods. (Of course, quantitative research methods may be used also when the previous premise is not true. This may, however, involve a painstaking process of manual data preparation from a number of different kinds of sources.)

In order to deal with the second viewpoint, explaining ICT in digital ecosystems theory, it is helpful to narrow the discussion down to a specific kind of ICT infrastructure. As pointed out before (D2.1), it turns out that Service Oriented Architecture (SOA) quite nicely matches digital ecosystemic thinking, as will be discussed further below.

5.4 Core DE Architecture and the Ontological Framework

Deliverable D3.6 (Moschoyiannis, Darking, et al, 2008) was the first document in a series of deliverables that aim to frame the interdisciplinary understanding and consensus in Digital Ecosystems research. In OPAALS the technological and social concerns in providing the necessary digital infrastructure are not treated as distinct but as part of the same continuum. Deliverable D3.6 set out the key concepts and characteristics of interest from a computer science and social science point of view. From the social science viewpoint it highlighted the issues regarding the policy domain in digital ecosystems and suggested areas of theoretical debate that opened up, culminating in the key concepts of open knowledge, power, control, and democratic processes which are at the centre of the ontological framework discussed earlier in this report. From a computer science viewpoint it discussed key design principles that have informed the design models of the core digital ecosystem architecture. These are: no single point of failure; diversity; reliability and distribution. For the social scientists this involves expanding discussion of these principles using social science theory and concepts alongside consideration of empirical data relating to the current socio-technical environment in which small organisations interact with one another, and potential digital ecosystem users.

The process of putting the design models and the social theories and arguments in a dialogue is iterative and requires an open debate that gradually includes more and more stakeholders. This process has been set up in OPAALS and in what follows we outline the consensus reached on key aspects of the core DE architecture, in terms of P2P and transaction support as well as distributed identity and trust models.

5.4.1 Support for distributed transactions

Previous deliverables of OPAALS (Deliverables D3.1, D3.2, D3.3) have reported on the work carried out by OPAALS computer scientists on a model for distributed coordination of long-running transactions and have highlighted how the proposed design allows for local coordination of the service executions involved. This ensures that local autonomy of participants is preserved and is achieved by using lightweight log structures given by directed graphs. The design of the required interaction scenarios, as shown in Moschoyiannis et al (2009b), is underpinned by a formal description of the behaviour and the executions patterns that services should follow in order to guarantee a successful outcome. In Moschoyiannis et al (2009a) we have also described how the required orderings of service invocations between the coordinator components of the local agents can be captured in *transaction scripts* and how the corresponding compensating sequences are determined. We have also outlined an extended lock scheme

for handling data dependencies during the execution of long-running transactions and their recovery whenever some failure makes this necessary (Razavi et al, 2007b).
Following lengthy discussions between social and computer scientists both face-to-face and via e-mail, it gradually became clear that the requisite need for sufficient stability, reliability and recoverability to support long-running transactions has been used as a justification for maintaining centralised, proprietary B2B systems. It was previously the case that only the computing capacity and resources provided by large technology companies were sufficient to achieve a sufficiently robust network. However, the approach taken by computer scientists in OPAALS among with latest advancements in distributed web applications shows that there are ways around this problem, which can remove the need for centralised command and control and its potential pitfalls.

Therefore, the distributed model for long-running transactions proposed in OPAALS has potentially extremely important consequences for unlocking the current B2B computing environment for SMEs. Although it cannot be presumed that a technology architecture can necessarily reconfigure human and business interactions, it appears, at the design level, that the transaction model holds significant potential to reduce the centralised and therefore potentially monopolistic nature of the current environment for B2B interaction. This raises an interesting point with respect to the approach to the socio-centric aspects of the development of the digital infrastructure for digital ecosystems. Here we have only touched upon the range of different approaches, from techno-determinism to socio-determinism, and this is a line of dialogue that will continue to occupy us in future work.

5.4.2 Distributed P2P network support

There is a consensus forming that peer-to-peer (P2P) solutions lend themselves naturally to digital ecosystem architectures. More specifically, we are interested in providing a fully distributed P2P network that can support complex interactions between the networked participants. A digital ecosystem is rather volatile, in terms of the characteristics of the participants (e.g. SMEs as opposed to large enterprises) and the interactions between them. This means that in addition to being fully distributed, the underlying P2P network should be highly dynamic in that its topology should continuously adapt to the actual usage made of the network. Moreover, a dynamic network topology is better suited to cope with various kinds of failure, which are likely in a highly volatile environment, especially when there is no central point of command and control.

Our approach to the underlying network design is based on clusters of nodes for providing permanent clusters, the so-called *Dynamic Virtual Super Peers* (DVSP), rather than permanent nodes as is the case with the super peers construct in conventional P2P networks. This work has been described in detail in Deliverables D3.1, D3.2, and has been subsequently published in peer-reviewed conferences and journals, including, but not limited to, the digital ecosystems community (Razavi et al, 2008a; 2008b; 2009).

Our focus is on providing support for transactions realising business activities and our design is targeted at achieving this without the need for intermediation by a (centralised) network operator. We show how the temporary networks formed by long-running transactions between existing partners can be used to boost critical characteristics of the P2P network topology such as stability and connectivity, which as we have seen are central to providing degrees of resilience against external or internal shocks. The proposed P2P architecture is based around the notion of the *Dynamic Virtual Super Peers* (DVSPs), which are aggregations of the most reliable nodes. Hence, the network is organised dynamically into layers of smaller and simpler networks formed by permanent clusters rather than permanent nodes (super peers). The formation of DVSPs evolves over time to adapt to the usage of the network and reflects the dynamicity of the DE environment.

The dialogue with social scientists in this respect focused on understanding the operational consequences of having virtual super peers for digital ecosystems users. This involved imagining scenarios of use and mis-use and asking the computer scientists to qualify and explain how technical procedures would be carried out. The main concern of the social scientists was that equity was maintained across the network. From this point of view, it was important to understand whether or not holding the position of super peer offered any operational advantage to an individual or organisation. In order to prevent domination or

potential monopolisation of the network it was important for the social scientists to establish whether there was any potential for exploiting the virtual super peer system.
In addition it was important to establish that all users regardless of size would be able to take advantage of the Peer-to-Peer network. One important question in this respect concerned the network's use of 'spare computing capacity'. There was concern from social science researchers that this would produce a barrier to participation for small companies who would be unable or unwilling to contribute spare capacity. Discussion around this centred on ideas of reciprocity and the need to cultivate the idea that in gaining use of the digital ecosystem it was necessary to contribute computing power, but that only spare computing capacity would ever be used.

5.4.3 Support for distributed identity and trust

In OPAALS we have also been concerned with the issues of identity, accountability and trust. This strand of research in digital ecosystems has focussed on how entities are identified in the DE and how trust is established between entities prior to engaging in transactions. Deliverable D4.5 has also explored the links between accountability and trust and the basis for underpinning trust with accountability data.

The governance requirements for digital ecosystems have always been a cause for significant debate and concern. Finding an organisational and decision-making framework that can mirror the decentralised, distributed attributes of the technological architecture is a major challenge and an area of innovation in and of itself. Legal requirements for underwriting contracts and guaranteeing operational aspects of the architecture can lead to an inflexible technology environment based on fixed legal entities. Although the overall characteristics of digital ecosystem governance will have a profound impact on the way trust, identity and accountability are managed, these socio-legal problems present one of the most significant sets of challenges.

5.5 A transformation matrix

The table below is a preliminary attempt to map the relation between the ontological categories of the digital ecosystems meta-theory with the socio-technical research performed so far in the OPAALS project and with the concrete technological output of the project. Both the socio-technical research and the technological development are going to continue in the third phase of OPAALS, following, mainly, the research trajectories delineated here. This transformation table, which shows how the three levels are interconnected, will be updated periodically in a collaborative way through the Guigoh environment of the project's online Open Knowledge Space (www.opaals.org.br).

Ontological Category	**Socio-Technical Research**	**Socio-Technical Outputs**
Knowledge	• DEAL and Agropedia case studies: analysis of different methods/tools for developing and sharing knowledge • Irish Biotech and Digital Media SME cluster case studies: analyses of the relationships between different knowledge bases, SME sectors, and possible DE usage • DEII: development of a methodology able to analyse the impacts of knowledge exchange (enabled by DEs) in terms of socio-economic benefits • Analysis of legal mechanisms for protecting knowledge creation and sharing • Analysis of OSS models for knowledge economic exploitation	• Knowledge sharing through Guigoh (document repository) • Information management systems provide versioning of data supporting archaeology of knowledge (OPAALS wiki) • Chat user profile personification in order to enable also informal interaction: Guigoh (informal/tacit knowledge) • DEAL and Agropedia DE-like environments

Discourse	• Research of the DE adoption process in the Trento province: localised definition of DE • Research on metaphors building inside Opaals research community • Analysis of the way in which the community defines digital ecosystems and OPAALS	• Online DE glossary • Visualisation of knowledge supporting the recognition of discourses
Power	• Analysis of governance models for DEs	• DE infrastructure: decentralised and distributed • DE identity model: decentralised and distributed • Tool for social network visualisation
Empowerment	• DEII: possible output in terms of empowerment (lowering knowledge asymmetries) for SMEs using DE • DEAL: empowerment of Indian farmers through DE for Knowledge usage	
Democratic processes	• Analysis on the relationship between digital ecosystems and Community Networks • DE adoption process in the Trento Province: participatory design and participatory decision-making mechanisms	• Symmetrical interactions tool without keystone entity, at least within certain classes of self-governing agents/ communities following an horizontal approach

5.6 Conclusion

The motivation behind the investigation presented in this chapter was to raise awareness of an extensive corpus of empirical and theoretical studies of social-economic ecosystems that has shown real benefit in informing decisions in the management of such systems. Our thesis is that much of this work can form the foundation for similar studies of digital ecosystems.

We can already draw some provisional conclusions that are informing our work in the OPAALS Network of Excellence, as discussed in Section 5.6. We have seen that a key impactor on resilience of an ecosystem is the ability of the species that interact in that system to be able to maintain key functions as conditions vary (Perrings, 1995). The concern with current digital ecosystems is that they are often, perhaps always, focused around a single or a small number of centralised hubs. This provides a fundamental limitation on the response diversity of digital ecosystems. As with any natural ecosystem (Holling *et al*, 1995), we believe that the "functional diversity of species that support critical structuring processes" (Brock, *et al,* 2002) is critical to the resilience of any digital ecosystem. Referring back to our view of enterprises as (one kind of) species within digital ecosystems, we believe that this requires us to develop digital infrastructures that respect and support the autonomy of small to medium sized enterprises (SMEs); the long tail of diversity in any resilient digital ecosystem (Razavi, *et al*, 2009).

Whilst some of the modelling from social-ecosystems may be directly relevant to digital ecosystems, there are some important distinctions too. For example, we mentioned that an agent might interact with more than one digital ecosystem. This is because in general, an agent may take multiple roles – a human agent, for example, may interact in a work related ecosystem, and an interest related ecosystem without cross-over between these roles. However, it is possible that one or more agents may identify a potential join between two previously separated ecosystems. As a concrete example, at the time of writing we are working to arrange funding to support a join between tourism and environmental/nature conservation digital ecosystems in India. This is an important form of innovation and can see the merging of two previously disjoint ecosystem ontogenies. We do not believe such mergers have so far been studied.

6. A Theory of Digital Ecosystems and the Process of Their Adoption

6.1 Introduction

> …it is important that in any discipline the community of scientific researchers revise, as individuals, groups and collectivities, their moral conduct and the ethical rigour of the internal rules of the game of the community in its implications for science and society, in terms of greater social responsibility and transparency (Vessuri, 2002: 146).

The above quotation is meant as a reminder that a theory of digital ecosystems cannot be separated from the actors who develop it and who may also be the same actors who apply it and enact it in regional deployments. In other words, the theory and the social processes surrounding the theory are intertwined – and the social actors involved are aware of this fact.

In this chapter we give a brief outline of the theory and of its application through a process of adoption of the digital ecosystems approach at the regional scale.

6.2 Towards a theory of associative autopoietic digital ecosystems

6.2.1 From research questions to hypotheses

Taking the steps from the definition of digital ecosystem provided in Section 2.2 and using a socio-technical approach (see D7.2), we may formulate the following research question as the main guideline for digital ecosystem adoption:

When (as opposed to What) is a digital ecosystem?[13] This question can be broken down into the following sub-questions:

- Who are the actors of digital ecosystem?
- What do they use a digital ecosystem for?
- How do they interact in the digital ecosystem and in the face-to-face environment (if any)?
- How do they self-govern? What governance framework applies to digital ecosystems?
- Which are the expected impacts in terms of socio-economic development for the users and for the regions?

These research questions guided and will continue to guide research on digital ecosystems adoption at the local level, but in order to be able to apply the epistemological framework delineated in this deliverable we may need to formulate specific hypotheses. What we are going to do is to operationalise the research questions in as many hypotheses as possible. Hypotheses should be at a lower level of abstraction compared to research questions in order to be testable (falsifiable) through field research that can then use different approaches in terms of investigation methods (qualitative and quantitative, interpretative or explicative, etc). Some of these hypotheses are already at the centre of OPAALS research, others can easily become part of the research agenda for future digital ecosystems-related projects at European and at local levels.

Hypotheses:

- A digital ecosystem is a socio-techical-economic process that – due to its characteristics – can find in SMEs, research groups, and knowledge-creating actors its main users,
- In a digital ecosystem, human beings interact with each other and with services that interact similarly among themselves,
- Digital ecosystems enable knowledge creation and diffusion of a specific kind: less vertical, easier to access compared to other socio-technical systems, facilitating the recognition by the users of the knowledge base they really need,

[13] To prefer questioning ‘when’ a DE is instead of ‘What’ a DE is, means to understand a DE not only as a technological environment, but as a social process. So a DE become a DE when specific local practices are generated as a consequence of its introduction. This approach to DE definition has been used in Botto and Passani (2008) and it is based on Star (1999).

- Digital ecosystems support knowledge exchange by lowering access asymmetries and by facilitating the transformation of tacit knowledge into explicit knowledge,
- Digital ecosystems enable multiple typologies of knowledge capitalisation (OSS as well proprietary software, etc),
- Digital ecosystems allow and enable the users to develop their specific governance model, whilst at the same time supporting and protecting principles such as democracy, moral equality and consensus building,
- Digital ecosystems foster local development in terms of:
    - economic growth increase in competitivenes for SMEs and the region
    - improvement in users/regional social capital
    - improvement of ICT usage at the local level
    - creation of new business models
    - improvement in regional international recognition
    - fostering participation and cultural expression.

6.2.2 Theoretical and applied processes

Figure 6.1 shows the dynamic and interconnected relationship between the applied research areas of OPAALS (articulated as research aims at the beginning of the project) and the theoretical research areas discussed in this chapter. The fundamental outcome of DE research (represented by the red text in the block on the far left) should be measurable and sustainable economic growth. Underpinned by questions of power (in terms of access to and distribution of information and technology resources), this is in turn dependent on social development, also informed by questions of power and empowerment. The right side of the diagram shows a fundamental starting point for any research effort aimed at constructing the technology necessary to enable human actors in achieving the outcome: knowledge. It is necessary to theorise what knowledge is, and how it is constructed, so as to be able to formalise that in language. And because as we saw in Chapter 2 we tend to favour Mouffe's view that knowledge is always plural and contested, rather than Habermas's view of the attainment of a uniform consesus, it is fundamentally necessary to collaboratively establish governance systems based on democratic processes that ensure all voices and versions of knowledge have an equal opportunity to participate in social development.

Figure 6.1 is also useful as an example of how difficult it is to integrate different epistemologies within the same argument. It is a very plausible proposition for any physical scientist and for many economists to say that the interdependencies present between the agents and actors in any economic systems can be conceptualised, and probably modelled, through non-linear mathematics. And yet, the introduction of the 'non-linearity' ontological category in the above figure is practically impossible without forcing a drastic reductionism on the other broad and all-encompassing concepts present. At this point in the development of our theory, therefore, we can do little more than derive the legitimacy of these different epistemological viewpoints from the legitimacy of these different forms of knowledge and, by implication, of the right of the respective practitioners to freedom of speech and expression. Hence the importance of democratic principles as a starting point. 'Democracy' here refers more to mutual respect and coexistence than to the reaching of a single decision by vote. In research and policy development agreement is best reached through collaborative and multi-stakeholder processes, which may result in a compromise, or in the inventing of a new solution together.

If by the above argument we have succeeded in establishing legitimacy, the next step is to embed each perspective in a methodological framework that leaves room for each viewpoint to pursue its objectives subject to empirical tests aimed at verifying, or falsifying, the hypotheses listed above. The work in the digital ecosystems projects up to now have, wittingly or unwittingly, operated under this general understanding.

A consequence of this diverse epistemological context is that we can only ever truly speak of a *process* of theory development, rather than of a complete theory. Hence, any sketch we offer at any point in time can only be regarded as a snapshot of a changing and dynamic picture, which will evolve and grow as new theoretical and applied collectives and individuals join the digital ecosystems knowledge communities and as new languages emerge to mediate new understandings. In light of this, Figure 6.2 shows an example of a possible integration of social and technical development processes that fit within the digital ecosystems approach and that contribute to the definition of our theory.

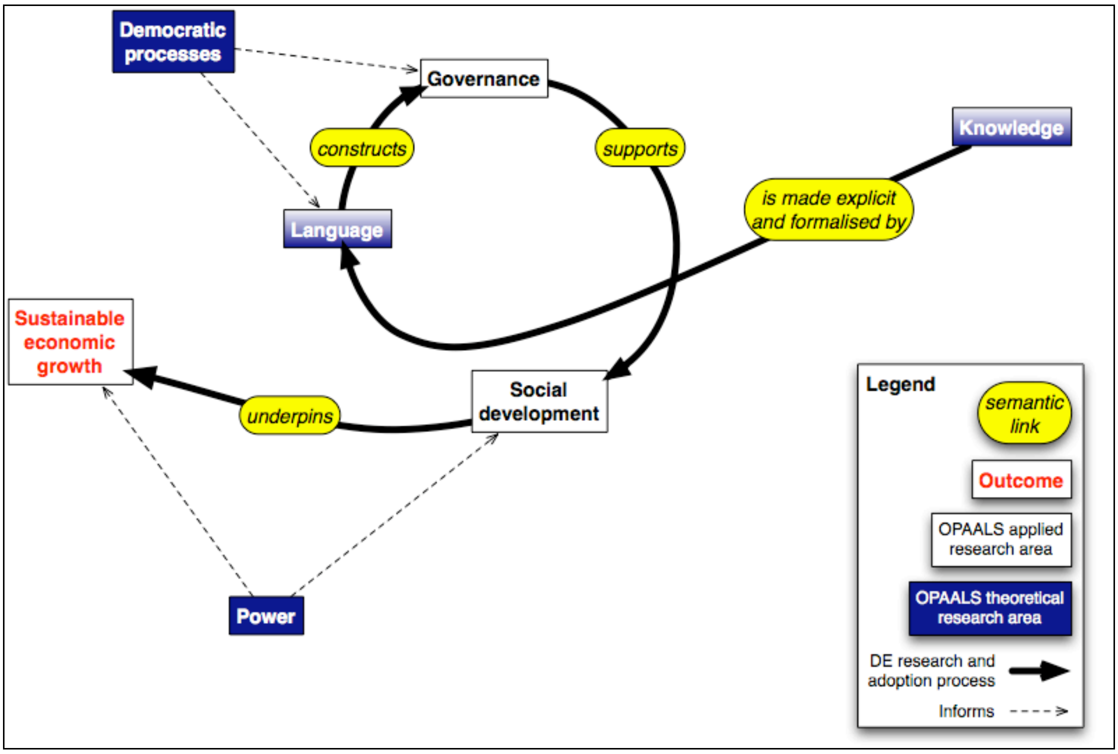

Figure 6.1: The dynamic flow of theoretical and applied research areas

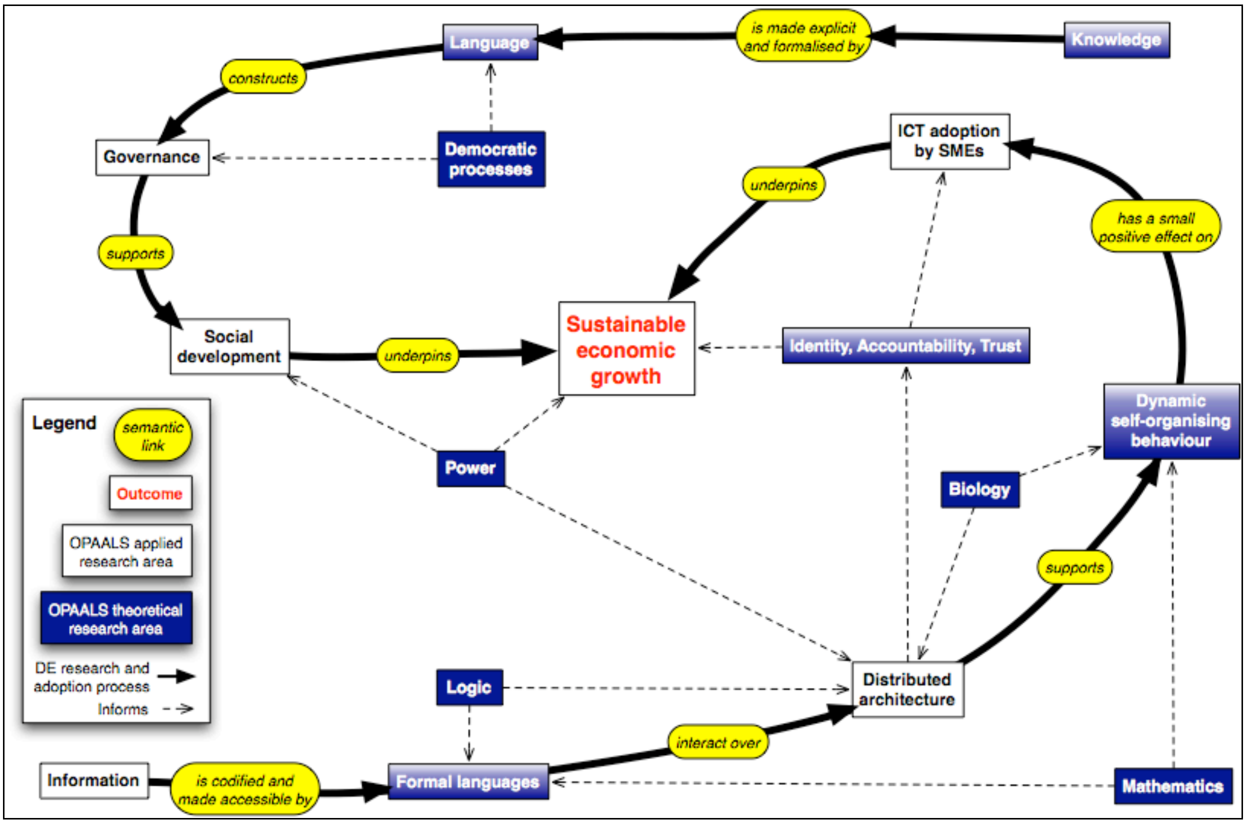

Figure 6.2: Socio-technical digital ecosystems processes

6.3 The process of digital ecosystem adoption

Digital ecosystem adoption (or deployment at local level, as in other documents) is a socio-technical process that finds its foundation in the ontological framework described in the previous chapters of this report. At the same time, it is a process consistent with the epistemological framework described. In fact, it is in the context of digital ecosystem adoption that the assumptions of the digital ecosystem theory can be 'tested' using the falsification paradigm introduced by Popper. In this chapter we first defined the hypotheses that have been/are going to be tested through concrete cases of digital ecosystem adoption, and we will now outline the process that can lead a region or a community to use a digital ecosystem in a self-sustaining way.

6.3.1 Towards a synthesis of the digital ecosystem adoption processes[14]

At the end of DBE project (Passani, 2007b) we defined the process of local adoption of digital ecosystems as one influenced by different variables, a process that needs to be adapted to local needs, user behaviour, and specific historical/economic junctures (see Figure 6.3). Although the digital ecosystem adoption process, as digital ecosystem technology, needs to be planned with the specific aim of being adaptable to specific local needs, we synthesised the process in the following sequential steps:

1. DE concept dissemination and awareness building
2. Socio-economic regional analysis: Regional/territorial Maturity Grade and/or DEII
3. Regional Catalyst definition and engagement
4. Industry/sector/community definition
5. Users definition (Cluster and SMEs identification and selection, or research community identification, etc)
6. Development of a shared road-map for the development of the first habitat
7. Training
8. Service development and ecosystem population
9. Pilot action evaluation (with DEII) and digital ecosystem systemic deployment planning
10. Steps from 3 to 8 can be replicated for different habitats adapting the activities to the specific needs of each industry/sector/community

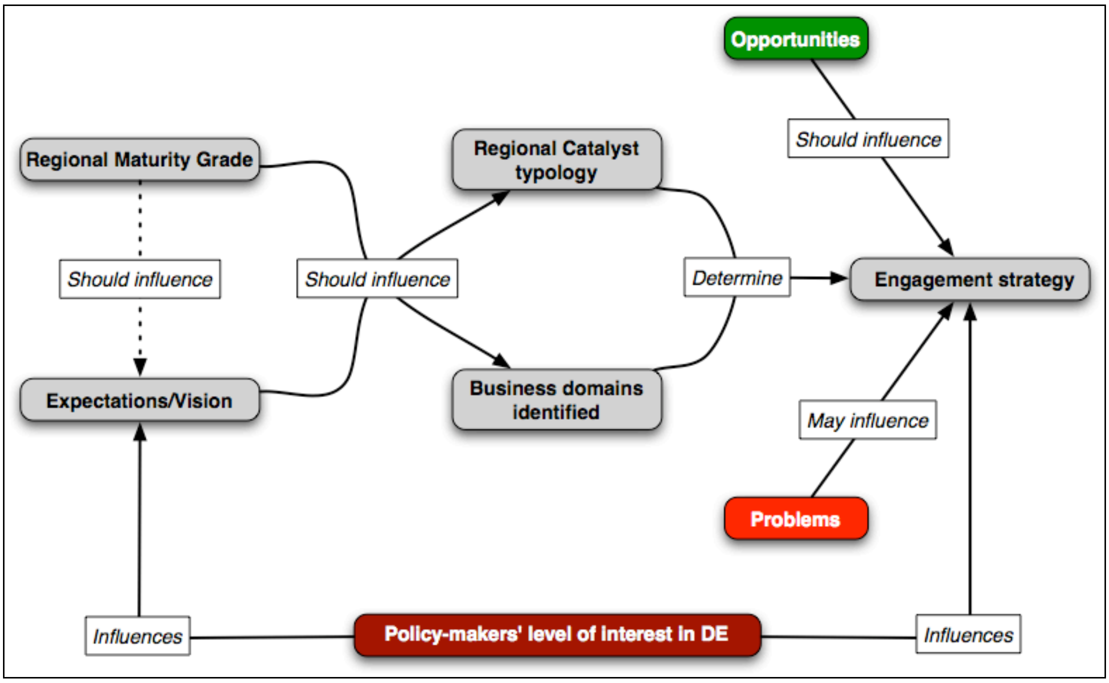

Figure 6.3: Local implementation process for digital ecosystems

[14] An important disclaimer is needed here: these process models are intended to be used by local stakeholders in a phase in which (as in the current one) the technology is not yet stable and the user community is still limited. Once the technology will be fully developed (both at the infrastructure level and in terms of basic services) the process will need to be fine-tuned.

This model, that has the positive characteristic of being easily understood by local stakeholders, is based on a useful, but problematic, simplification: it is mainly based on a linear process. In D12.7 an addition to this model has been proposed (Szabo and Botto, 2008). In this complementary model, the concrete actions to be taken at local level are analysed in depth and a participatory methodology is suggested. Thus, in this second approach the top-down nature of the first model is mitigated, and the local community (future users) gain a bigger role in the digital ecosystem definition process. The top-down element of digital ecosystem adoption, however, cannot be eliminated, due to the fact that digital ecosystem deployment at local level is undoubtedly a political action that needs to involve policy-makers and to be connected to the institutional process of innovation policy development (this is particularly true at the present stage of digital ecosystem technology development). Szabo and Botto (2008) suggested consideration of the following points of attention:

- Start from concrete local needs
- Work with people at many levels: after the policy makers, innovation should involve both the management and the lower levels of business organisations and communities
- Work on what makes sense for participants, not only on the digital ecosystem idea: instead of 'implementing' a digital ecosystem (or a digital community ecosystem) as the core objective, focus on developing meaningful innovation for the community and use the digital ecosystem ideas as a tool
- Avoid using the term "digital ecosystem" or "ecosystem": the result of this innovation should be something meaningful for local communities also in its label. It is improbable – but not impossible – that they will adopt their own vocabulary.

In this model, therefore, the top-down approach meets the bottom-up processes that always exist at local level, and the Regional Catalyst becomes the principal actor responsible for the grey area in the middle, in which the institutional level needs to meet the necessities and aspirations of the community level (this is an abstraction of the concrete process being followed in the Trento region, for more details please see D12.7 and D12.8).

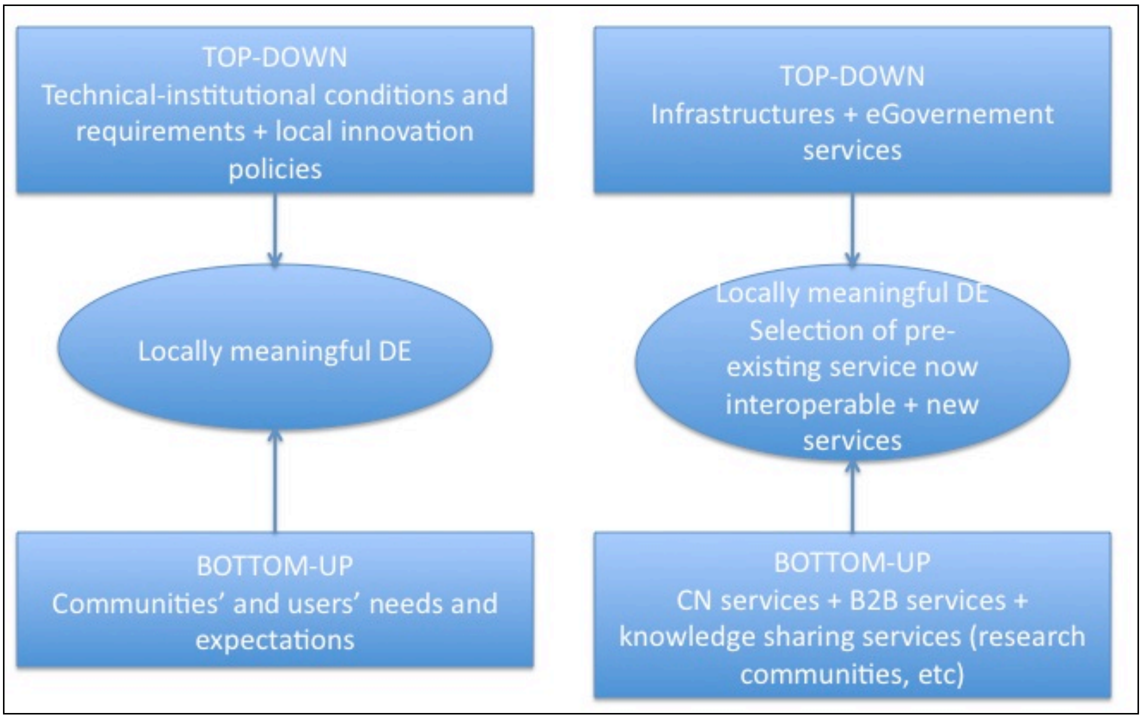

Figure 6.4: Abstraction and further development from Szabo and Botto (2008)

The role of Regional Catalyst, in this model, is that of translating the digital ecosystem research into the 'local language' and of facilitating the process of bottom-up introduction of digital ecosystem. The process here described shows important similarities with the hermeneutic approach described in Chapter 3

and can be seen as an application of the Participatory Design and Action Research ideas to a complex local innovation process, as shown in Figure 6.5.

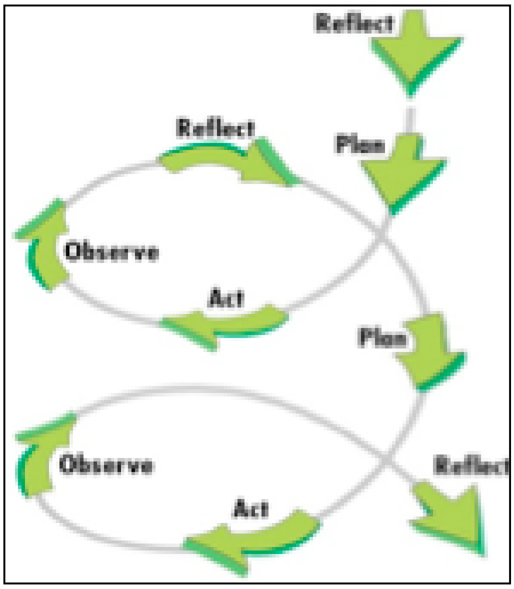

Figure 6.5: Schema of action research and participatory design circular iterated process (Source: D12.7)

The sum of the two digital ecosystem adoption models accounts for Foucault's discursive approach by taking in consideration the definition that local actors give to a digital ecosystem. In addition, it also acknowledges issues of power and democratic processes by introducing participatory decision-making processes.

In this new approach to DE adoption, partially already tested in Trento and in Lazio regions, we can see a better balance between the top-down and the bottom-up approach and the role of Regional catalyst evolved significantly.[15] In this model the knowledge generated by the OPAALS project (and other projects in the digital ecosystems cluster) reaches beyond the local level because the complexity of the language layer of innovation is well acknowledged. The local digital ecosystem adoption can be seen as a process in which knowledge is provided by the research community to local stakeholders that then can use it for creating new knowledge, accordingly to their concrete needs. In Phase III of OPAALS WP 11 and WP9 will provide communication and dissemination material able to support the process at local level. At the same time, the DEN4DEK project (in which OPAALS partners are represented) is supporting European regions in introducing the digital ecosystem concept in their innovation policies approaches in a formal and institutionally soundly way.

Power asymmetries (between the institutional and the user layer on one hand and between knowledge providers and users on the other) are also acknowledged and mitigated thanks to participatory decision-making process (participatory development of a digital ecosystem adoption roadmap) and participatory service development. The discourse layer is also taken into account enabling and facilitating users to develop their own definition of what a digital ecosystem can be for them.

Figure 6.6 shows a global summary of the participatory process of DE adoption (please refer to D11.8 for a more detailed description).

[15] It is important to notice that the role of Regional Catalyst can be played in a collaborative way by more then one local actor. For example a local development agency can act as RC in the first steps of the process positively engaging the institutional level, then a research centre or an innovative software enterprise can take action as Regional Catalyst when dealing with participatory service design. This issue has been already covered during the DBE project, see D31.6 (Passani, 2007b).

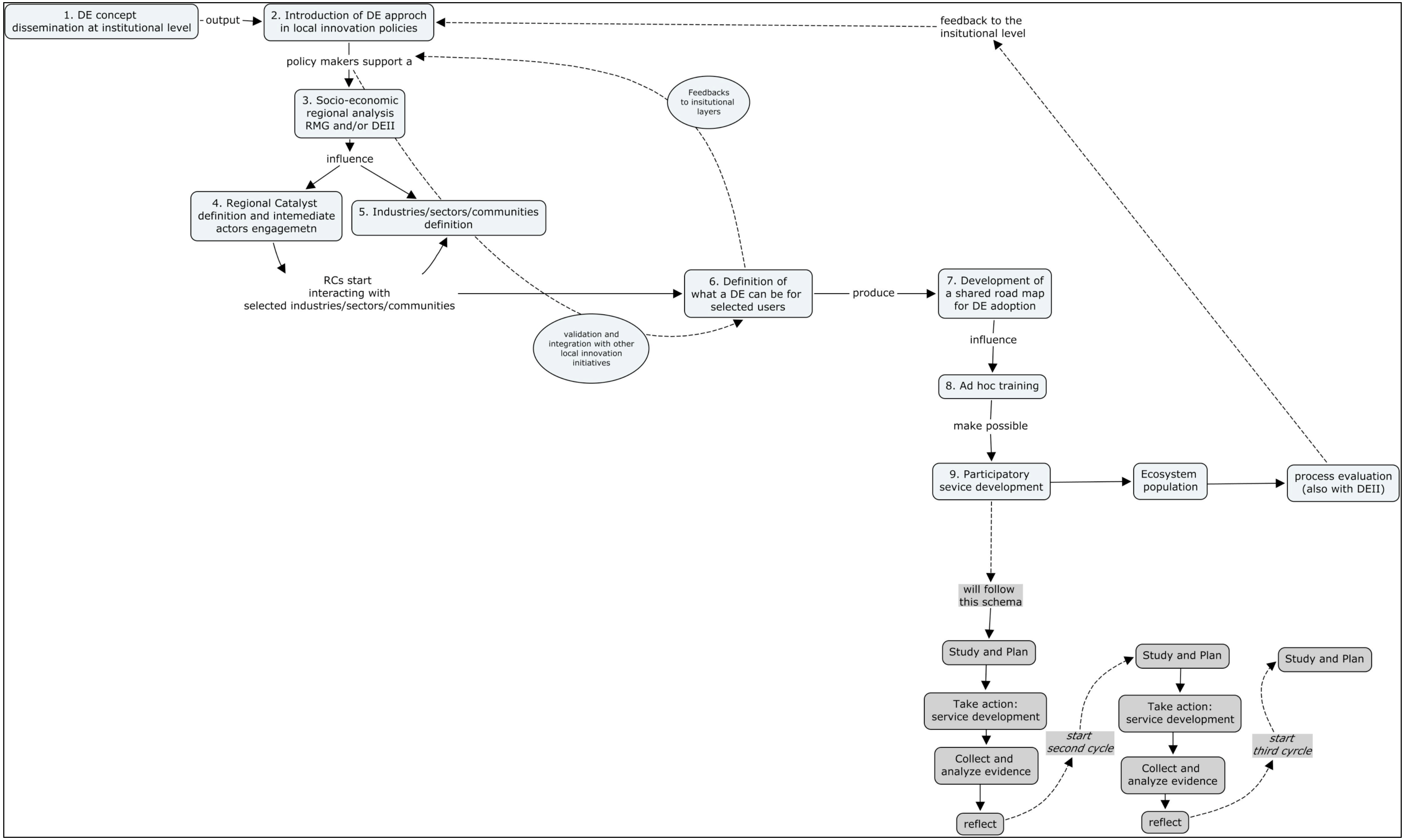

Figure 6.6: Participatory process of DE adoption

7. CONCLUSION

As already stated in previous chapters, the theory of digital ecosystems we are developing should be understood to have emerged from a project, or set of projects, funded by the European Commission in the context of the Information Society agenda and of neoliberal norms. That this is the case can perhaps be seen best through a thought experiment.

In reference to Figure 6.1 or 6.2, we see that the overarching (falsifiable) objective of the whole effort is sustainable economic growth, which is consistent with the EC's Information Society agenda. Thinking back to the various epistemological categories we have explored in this report, we can see that whereas we have discussed various epistemologies grounded in democratic process, language, biology, physics, and mathematics, we did not attempt to construct an epistemology of economics.

The thought experiment is to remove the "sustainable economic development" box from Figure 6.1 or 6.2, such a removal signifying the disappearance of all economic concepts from our conceptual vocabulary. The result is an uneasy sensation of void. The whole effort appears to lose a good part of its meaning. Of course, in this and in the hundreds of reports we have written in the past 6 years in various digital ecosystems projects, we have emphasised concepts such as the importance of collaboration, of social networks, of knowledge, of cultural values, of creative expression, of language and communications, and of self-determination. And yet, even if we take 'economic growth' in its most reductionist, restrictive, and functionalist sense, without it a good part of the meaning of the digital ecosystems research effort disappears. This is a simple-minded demonstration that economics as we currently understand it, even in its narrowest sense, is one of our implicit and pervasive epistemological categories – so much so that it has become invisible: we don't notice it until we take it away and the whole house of cards starts to teeter.

But we have also more positive conclusions to make. The effort to bring together apparently irreconcilable epistemologies has been enormous and of still-uncertain outcome, but it led us to propose a meta-epistemological framework that seems serviceable. The true test of our theory, however, will be in seeing whether the theoretical apparatus we have constructed can renew itself under the inflow of new ideas and perspectives from inside and outside Europe, in order to initiate and support an autopoietic process of theory construction leading to a theoretical system with a recognisable identity.

We may be tempted to map Luhmann's autopoietic system of communications to an autopoietic system of theories. At some level of abstraction it may be possible to argue that the 'life' of such a system of ideas, i.e. its autopoietic properties, will depend on properties of the 'theoretical citizens' populating such a system that are analogous to the accountability, transparency, trust, participation, responsibility, engagement, and collaboration of the individuals participating in the construction of the theory. The application of this model to other contexts could then lead to the emergence of new associative and autopoietic theories of democracy, or new associative and autopoietic theories of economics, through a similar level and quality of participation by the individual 'social constructors'.

The result of our theoretical effort, therefore, appears to be the tentative definition of an associative and autopoietic *theoretical* ecosystem as a necessary complement to the introduction and continued development of associative and autopoietic *digital* ecosystems in various theoretical and applied contexts.

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APPENDIX A: DISSEMINATION PAPER ON DIGITAL ECOSYSTEMS

A.1 Digital Ecosystems Explained[16]

A Digital Ecosystem (DE) is a peer-to-peer, open-source environment that enables communities of interest to work together online. The technology has been developed by a consortium of computer and social scientists in a research project funded by the European Commission, and titled Open Philosophies for Associative Autopoietic Digital Ecosystems (OPAALS).

OPAALS was established in 2006, and built upon the research of previous projects, including Digital Business Ecosystems of 2004 – 2006. The aim of OPAALS research is to develop the technology and theoretical framework for Digital Ecosystems and by so doing contribute to a radically different vision for the future of the Internet society. With members who have regional economic development responsibilities and direct contact with small businesses and end-user communities, OPAALS brings together viewpoints that range from the theoretical bases of Digital Ecosystems to the use cases of the final application. Known as Regional Catalysts, these individuals provide a direct link to end-user communities and have the contact and the social capital to involve such communities in early-stage Digital Ecosystem research and use.

The central output of OPAALS, which concludes in May 2010, is the online technology for Open Knowledge Spaces, the first of which has been developed as a collaborative knowledge creation and sharing space for Digital Ecosystems researcher communities. This online environment – in some ways similar to social networking sites, yet integrating business oriented, collaborative document creation and management, conferencing tools and also online transaction functionality – will sit on a truly peer-to-peer network. The distributed nature of the environment avoids the risks associated with the proprietary, central server style networks that govern the Internet at present. The avoidance of a central point of control and failure is therefore a key advantage to small players, such as academics, small businesses or entrepreneurs.

All of the research outputs created by OPAALS are available for use by other communities or researchers. The models created and lessons learned in contributing to the development of an open-source, peer-to-peer information technology system that facilitates productive exchange among communities of interest is available here: http://wiki.opaals.org/DeliverableAbstracts.

All of the technologies developed by OPAALS are open source, and are therefore not only free to use, but open for contributions and adaptation by other computer scientists (on the condition that the outcomes of that adaptation is similarly made available to others in an open source manner). In fact, anyone can join the Open Knowledge Space and use it to share their research, connect with other researchers, establish communities and learn from others. Digital Ecosystems technology is not therefore a proprietary model, and can be used by any community or network of interested parties to service their own socio-economic goals.

[16] Adapted from Deliverable 9.12.1

A.2 The elements of a Digital Ecosystems community identity[17]

We are a collaborative community

OPAALS is a network of people from organisations of many kinds, and from many locations, who are actively involved in defining the leading edge of the emerging science and technology of Digital Ecosystems. The network facilitates us collaborating, cooperating, communicating and sharing as a group and a community.

We believe that we will cause radical change

We believe that Digital Ecosystems will cause a global paradigm shift in information technology and associated social development. In ways as yet undreamed of, it will change both the economic and social landscape.

A child of the Internet revolution, it represents the next generation of ICT use: one which could not have been conceived without the interconnectedness of today's society, though one which is not a linear progression, but an entirely new mixture of genes and which, with our nurture, will grow to improve the lot of humankind.

We are from different backgrounds

We are an eclectic mixture, consisting mainly of researchers and economic development actors. The researchers come primarily from three established domains: computing, social science, and to a lesser number, natural science. The economic actors are mostly regionally based and concerned with ICT adoption and development in their region. This unusual mix of science and economic development is necessary since the science cannot progress without users and vice-versa.

We are open, democratic and sharing

Network membership is open and therefore constantly changing. There is no divide between inside and outside in our network. There are no fixed rules. Members may take passing interest and use our work, or become deeply involved in contributing to the science and the application. We are a meritocracy: a role in the network is whatever each member, in collaboration with others, wants and allows it to be. We are constantly developing and implementing a concept of democratic process that we all feel happy with.

We are global

Any organisation in the world may come into our network, and we have active participation internationally. We welcome the widely different perspectives this brings to the potential applications of Digital Ecosystems.

We link science with regions and end-users

By incorporating members who have regional economic development responsibilities and direct contact with small businesses and end-user communities, we are able to benefit from a panoramic viewpoint that covers everything from the theoretical basis of Digital Ecosystems to the use cases of the final application.

The Digital Business Ecosystems project pioneered the concept of Regional Catalysts who provide the direct link to end user communities and have the contact and the social capital to involve such communities in early stage use and even in research.

[17] From Deliverable 9.7

We are interdisciplinary

Digital Ecosystems, while physically based on Information and Communication Technology (ICT), represent far more than the interconnection of machines. There are powerful social mechanisms that cannot be avoided, as well as economic implications. There is also the natural science surrounding the phenomena of ecosystems: whether that science is biological or physical or mathematical.

We strive to be truly *inter*-disciplinary rather than simply *multi*-disciplinary. This is one of our greatest challenges - to move people to work in the spaces between disciplines rather than simply connect disciplines together with researchers remaining on their home ground.

We connect to other research

OPAALS was formed as the result of the European Union R&D Framework Programme, under a specific theme to create Networks of Excellence (NoEs). We participate in clusters of similar European projects and are open to cooperation and links with any complementary project.

We also participate in and associate with projects of international cooperation in R&D and ICT development in order to build our global knowledge and influence.

We recognise the political dimension of our work

We are apolitical in the nationalistic, governmental, or party sense. However, we recognise that Digital Ecosystems have a potential effect, and even a role in history, to change the balance of social order from globalisation involving large and centralised oligopolies, to small, decentralised, and democratic entities that have global reach. With our contributions, the inequality within current economics that enables monopolies to be created from de facto lock-in to proprietary products will shift significantly.

We work on trust

Trust forms the fundamental principle upon which everything related to OPAALS will always be based. We each have a responsibility to protect each other, as individuals and as a community. Trust and the obligations it brings come before everything else.

You can participate in the network

Participation is open and free. There are no mechanisms. We are a community and so a new member must gradually come to know and interact with that community.

Our rights within the network

We expect every participant to treat every other participant with respect and courtesy. We expect the behaviour of participants to be responsible and ethical in terms of their native culture, to be sensitive to the cultures of others, and to adapt to the emerging ethic of the group.

The rights of the network

No individual or organisation represents the whole network. We have the right to speak openly and freely to represent our own views, but we do not have any right individually to assume representation of the network to the wider world.

The graphical images and identity statements may be freely used and adapted by anyone who regards themselves as an active member of the OPAALS network, provided it is not used such that it may be construed as indicating endorsement, ownership, or formal representation of the network.

Intellectual property is important to us

We respect all intellectual property rights. We encourage and expect participants to publish using a derivative of the General Public Licence or Creative Commons as appropriate.

We change, we adapt

Just as a Digital Ecosystem is a complex adaptive system that can change, so the OPAALS network adapts and changes. Thus there is no rigid program, no grand design. While we do not know what the future holds, we do believe we have the conceptual and practical framework of an organizational identity to be ready to embrace it.

APPENDIX B: GLOSSARY OF DIGITAL ECOSYSTEMS TERMS

The following glossary was collaboratively assembled by the OPAALS community, and represents the beginning of a growing, interdisciplinary lexicon of terms specific to digital ecosystems research. Entries are drawn from a variety of sources in the Open Knowledge Space (existing project deliverables, the project wiki, collaboratively edited documents on Guigoh), as well as from existing scholarship where appropriate.[18] It is thus a work in progress, and is expected to grow and expand along with the OPAALS community and the digital ecosystems field of research. It is included in this deliverable to indicate progress towards the ongoing elaboration of a self-defined and assembled glossary of terms relevant to a digital ecosystem community.

Term	Definition
Adaptive	Ability of a system to respond to changes in environment by modifying itself. These modifications can be manifold and uncertain and do not need to be deterministic. However, an adaptive system can also change itself through clear and definite rules how to modify according to certain changes of the environment (determinism).
Associative system	If an autopoietic system is one that recursively self-organises through the complex, adaptive interactions of groups of agents, an associative system can be defined as one with those processes as well as, crucially, a high degree of cooperation between agents in the project of reaching those goals and reflexivity about the processes and attempts at reaching them. [...] An associative system is one that chooses (through its agents' agency) to explicitly include qualities such as rationality (knowing why and how), explicit verbal commitment (deeds speak for them), trust and altruism (Axelrod, 1984: 173-4) in its forms of cooperation. (D12.1)
Autonomous	A property of an entity: Autonomous entity is self-sufficient and therefore does not depend on other entities.
Autopoiesis	Self-producing systems. "A composite unity whose organisation can be described as a closed network of productions of components that through their interactions constitute the network of productions that produce them, and specify its extension by constituting its boundaries in their domain of existence" (Maturana, 1987: 349). Self-manufacture with the recursive ability to spawn more copies of oneself, each of which embodies the same ability, recursively. (D1.2)
Community Network	"Community networking has its origins in services such as the Free-Net, which emerged in the '80s and early '90s to offer online access, sometimes along with local news and information" (Shapiro, 1999). Two main understanding of CNs could be considered. First, traditionally one refer CNs to the grassroots bottom-up movements promoted by Schuler: "New computer-based community networks are a recent innovation that are intended to help revitalize, strengthen, and help expand existing people-based community networks much in the same way that previous civic innovation have helped communities historically." (Schuler, 1996:25). Second, in the last years CNs is referred to telecommunication infrastructures created and owned with the core participation of a local government (see: Chlamtac, Gumaste and Szabo, 2005).
Democratic process	A course of action aimed at framing the challenges of governance that arise from diversity, which can be understood to operate on various levels: cultural, social, linguistic, theoretical, philosophical, epistemological, and so on. The area of social theory involves conceptualising, based on a fundamental assumption of equality, diverse actors can live and work together as a community.
Determinism	In biology, the concept that the fate of an organism is determined by a pre-existing set of instructions. In its crudest expression the approach would assume that a person's destiny was entirely dictated by the nucleotide sequence in their DNA. The concept crops up in a variety of disguises: in E.O. Wilson's writings on socio-biology; in Richard Dawkins' notions concerning selfish genes and the origins of altruistic behaviour. It is a form of reductionism and is in direct opposition to concepts such as vitalism. The idea that all of cancer can be understood in terms of the molecular biology of genes and DNA is a deterministic belief that, so far, has produced little in the way of practical benefits. (D1.2)
Digital Ecosystem	A Digital Ecosystem is any distributed adaptive open socio-technical system, with properties of self-organisation, scalability and sustainability, inspired by natural ecosystems.
Empiricism	Empiricism holds that general theories can be inferred from many empirical examples or facts through induction, and prioritise applied real world research in order to gather data that can

[18] Please note that the works cited in this glossary are not included in the deliverable references list.

	allow for such theorisation.
Epistemology	"A philosophical concept meaning the theory of knowledge, which underpins methodology. For example, the type of methodology employed in a piece of social research will be determined by epistemological assumptions" (Bilton et al., 1996: 658; D1.2).
Evolution	Change over time arising from a background of natural selection ("survival of the fittest"). In social context the term "evolutionary" is strongly related to the term adaptive. The attribute "evolutionary" characterizes those processes which change a certain social system in respect to the environment. Such a system is not static but flexible and adaptive which allows the system to react on changing conditions and to sustain a changing environment. Because the changes do not need to be deterministic but can be open and manifold the sum of all processes in all equal systems can be regarded as evolutionary. The term adaptive characterizes a system. The term "evolutionary" characterizes the related processes which make a system adaptive.
Free Networks	A Free Network is any computer network that allows free local transit, following the guidelines of our peering agreement. By "transit", we refer to information flowing through the network. While most of our members specialize in wireless networking, a FreeNetwork can be built using Ethernet, fiber optics, or any other kind of networking technology. A FreeNetwork is defined by what its users can do with it, rather than the particular technology it is built on (freenetworks.org). However, in this context, it may bemore interesteing the concept of Scale-Free Networks. A scale-free network is a network whose degree distribution follows a power law, at least asymptotically. That is, the fraction P(k) of nodes in the network having k connections to other nodes goes for large values of k as $P(k) \sim k{-}\gamma$ where γ is a constant whose value is typically in the range $2<\gamma<3$, although occasionally it may lie outside these bounds. Scale-free networks are noteworthy because many empirically observed networks appear to be scale-free, including the world wide web, protein networks, citation networks, and some social networks.
Free/Open Source	The term 'Free/Open Source' describes: * Software protected under special copyright licenses aiming to ensure the availability and free (re)distribution of the source code. Source code refers to the set of instructions written by developers that make up a program. Proprietary software is distributed only in the form of object code, the machine readable translation of the source code, which is required for computers to run programs. Open Source software is distributed both as source and object code. * A process of software development that incorporates some unique characteristics, such as the ability of users to suggest new features, report faults in the programs, etc. * A movement based on the ideals of the hacker culture which is premised upon the freedom to use, create, and tinker software and the values of gift culture, such as the ideal of reciprocity (Kollock, 1999).
Functionalism	"A theoretical perspective, associated with Durkheim and Parsons, based on an analogy between social systems and organic systems. It claims that the character of a society's various institutions must be understood in terms of the function each performs in enabling the smooth running of society as a whole" (Bilton et al., 1996: 660; D1.2).
Governance	"The process of the enacting of policies and decisions on the part of officials within a political apparatus. We can speak of 'government' as a process, or the government to refer to the officialdom responsible for the taking of binding political decisions. While in the past virtually all governments were headed by monarchs or emperors, in most modern societies governments are run by officials, who do not inherit their positions of power but are elected or appointed on the basis of expertise and qualifications" (Giddens, 1997: 582; D1.2)
Hermeneutics	Hermeneutics essentially takes as fundamentally significant the various forms in which human understanding (of art, communication, social life) manifests itself (Gadamer, 1976: 18). Central to this position is language (or as Gadamer (1976: 19) puts it, "the universal phenomenon of human linguisticality"), and the ways in which it mediated individual understanding and interpretation of social experience. Ultimately, the argument of the hermeneutic position is that human understanding of everything in the world is carried within language. Rooted thus in philosophies of the aesthetic and rhetoric, hermeneutics implies that "the grasping of the meaning of the text takes on something of the character of an independent productive act" (Gadamer, 1976: 24). (D12.10)
Identity	"Normally used in social sciences with relation to self-identification of groups or individuals. Conscious beings and things which contain conscious beings as members, such as societies, institutions and organisations, have identity. This can be seen as the ability to communicate the fact of existence and belonging" (Scruton 1996). "Not something which is natural or fixed, but something that evolves within a cultural context" (Stevenson 2003: 156; D1.2).

	In computer science: Identity is usually used for authentication and authorisation, In social science: Identity is an umbrella term used throughout the social sciences to describe an individual's comprehension of him or herself as a discrete, separate entity.
Individualism	A branch of social theory that takes the individual as the focus of social action. The attitude that indiviudal personhood and rights take precedence over all collectives in moral and political decision making.
Institution	Widely defined by the OED as 'an established law, custom, usage, practice, organization or other element in the political or social life of a people; a regulative principle or convention subservient to the needs of an organized community or the general ends of civilisation'. (Scruton, 1996)
Isomorphism	A one-to-one correspondence between the elements of two sets such that the result of an operation on elements of one set corresponds to the result of the analogous operation on their images in the other set.
Knowledge	Knowledge is a state of consciousness, which is a mental image of a reality within or outside the knowing subject. In general this image of reality is regarded as true but the valuation of truth can differ from individual to individual. Knowledge arises from the interpretation of information and/or from the linking of information with other knowledge. Regarding the sum of individuals who share the same image of reality, knowledge has a social validity and diffusion. Only living beings can store knowledge as it is bounded to their mind. That's why the successful transfer of knowledge relies on an appropriate, reversible and reliable transformation from knowledge into information/data and the retransformation respectively interpretation from information/data to a corresponding state of consciousness.
Knowledge management	Knowledge management embraces those processes, practices and systems which are developed to support systematic and successful knowledge transfer.
Knowledge transfer	Knowledge transfer is communicative process in which knowledge is transferred from one individual (sender) to an other (receiver). Basically this transfer relies on the explicit creation of information which is an abstract and transferable representation of the sender's knowledge. This information needs to be interpreted by the receiver to constitute new knowledge at the receiver. The creation and the interpretation of information however are not unequivocal. That's why the success of knowledge transfer is not clear and hard to measure. (PIIIKO)
Logic	The study of the principles of reasoning, especially of the structure of propositions as distinguished from their content and of method and validity in deductive reasoning. (JOIE)
Network	A structure of interconnected entities
Objectivism	Objectivism considers that "the object (society) predominates over the subject (the knowledgeable human agent)" (Giddens. 1984: xx)
Open Knowledge Space (OKS)	An Open Knowledge Space (OKS) is a scalable society of distributed knowledge spaces An OKS has multiple users and communities that can interact with each other whenever they are online and form a peer-2-peer network of knowledge's spaces that can be semantically searched based on their availability (i.e. if they are online) and the amount of mutual trust they have acquired. The OPAALS Open Knowledge Space (OKS) is a collaborative knowledge creation and sharing space for the Digital Ecosystems, multi-disciplinary research community as well as SMEs. It provides a 3D navigation of semantic networks of the many ontological categories that make up the OKS's body of knowledge, including expertise, disciplines cultures and geographical locations. It provides users with their own personal customisable research space, the ability to collaborate with others in similar networks and thus continue the process of knowledge and network generation that is part of a knowledge society. The OKS is built on an open source, distributed, peer-to-peer architecture and its recursive and self-reinforcing nature is inspired by biology and enabled by the capabilities of semantic web technologies.
Ontology	In social science, a branch of philosophy that deals with the nature of existence. In computer science, a data model that represents a set of concepts within a domain and the relationships between those concepts.
Open Innovation	The use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively It is the antithesis of the traditional vertical integration model of industrial innovation. While the contours of the new model of innovation remain obscure, it is clear that an adequate understanding will require a more externally focussed perspective, involving the actions of multiple actors in a far more distributed innovation environment. (Chesborough, 2006).
Peer to peer (P2P)	A network structure in which transactions occur between peers.
Peer to peer	A flexible network of intelligent machines relying on digital technologies without a central

infrastructure	point of dependence or failure. Alternative to client-server architecture.
Peer to peer network	Decentralised, horizontal, computer-to-computer network without a central point of dependence or failure.
Phenomenology	Phenomenology began as the theory of 'consciousness as such', studied in isolation from the material circumstances that surround it; the hope was to determine the nature and content of the various 'mental acts'such as belief, emotion, thought and desire. The term was later used to name a somewhat diffuse method in sociology, which stays with the description of the perceived surface of social phenomena, believing that social consciousness represents the world in a unique way, and that until we understand the mode of 'representation' that is intrinsic to it, it is pointless to look beyond it to the material facts which provide its explanation, since we will not know what we are trying to explain (Scruton, 1996).
Positivism	Theories based on observation of that which really exists and is observable, certain schools of sociology which concern themselves with questions of method and regard their subject matter as social facts, and seeking to avoid scientific explanations of a normative nature (Scruton 1996).
Rationalism	The philosophical theory that the world is knowable to reason, and only to reason, and that the deliverances of the senses stand to be corrected in the light of reason. ... More widely, 'rationalism' is used to denote the disposition to favour clear and explicit solutions, based on principles, whatever the problems, and to attemt to force reality into the mould of an ideal of reason-governed behaviour. (Scruton, 1996).
Reflexivity	The ability to self-inspect, and to be aware not only of the impact of one's views, epistemologies and methodologies upon oneself, but also the social environment within which one is working or living.
Self-organisation	Ability of a system to re-arrange its components (internal structure) without outside control or influence.
Semantic Web	A common framework that allows data to be shared and reused across application, enterprise, and community boundaries. W3C Semantic Web is a collaborative effort led by W3C with participation from a large number of researchers and industrial partners. It is based on the Resource Description Framework (RDF).
Single Point of Control	This concept is quite related to "single point of failure. It means that controlling one point of the network, it is possible to control the entire network. Then, networks with a single point of control are easier to be manipulated and brought down.
Single Point of Failure	A Single Point of Failure, (SPOF), is a part of a system which, if it fails, will stop the entire system from working. They are undesirable in any system whose goal is high availability, be it a network, software application or other industrial system. The assessment of a potentially single location of failure identifies the critical components of a complex system that would provoke a total systems failure in case of malfunction. Highly reliable systems may not rely on any such individual component.
Social science	According to Anthony Giddens, "social practices (reproduced across time and space) should be regarded as the basic subject matter of the social sciences" (Giddens, 1983: 77). Social sciences seek to understand how human beings construct, interact with and understand themselves and their (social) environments. This could be summarized as an opposition between a kind of mechanical objectivity and a kind of hermeneutic relativity. The social sciences could be said to construct knowledge from a process of observing and engaging with inevitably subjective human experiences and contexts. This compels "the recognition of the hermeneutic nature of social description" (Giddens, 1983: 77). Social science research is bifurcated into plural processes of seeking plural meanings from an infinite number of potential perspectives. These methods of social research can be so different, e.g., qualitative and quantitative, that they often appear to be intradisciplinarily at odds with one another. In this sense, in practice as well as in definition, social science is innately relativist and can be manifested in multiple ways.
Subjectivism	Subjectivism concerns itself with "a social world in which the categories of experience were already formulated by and in the 'meaningful conduct' of human subjects" (Giddens, 1995: 178). In other words, pure observation of social events involving human actors is insufficient, and more attention should also be placed on hermeneutic understanding. (D12.10)
Sustainability	Ability of an (eco)-system to maintain itself and its properties.
Trust	The management perspective defines trust as "The willingness of a party to be vulnerable to the actions of another party based on the expectations that the other party will perform a particular action important to the trustee, irrespective of the ability to monitor or control that other party" (Mayer, Davis, and Schoorman, 1995).

APPENDIX C: INTERNAL REVIEWERS' COMMENTS

The following pages contain the written internal reviews from Profs Hebe Vessuri and Irene Plaz Power, Venezuelan Institute of Scientific Research, and from Prof Joe Wallmannsberger, UniKassel.

Comments to the OPAALS Third Report D12.10

Hebe Vessuri and Irene Plaz Power

If we take a multi-theoretical and dynamic perspective, theories as well as understanding appear as interpretations of reality. We theorize and understand situations in the same way as we try to formulate images and explanations that may help us to make an idea of the fundamental nature of the situation. An effective way of doing this is by taking into account rival explanations and theories rather than staying attached to a fix unmovable viewpoint. Theories and explanations are based on metaphors that see and understand organizations in different and partial ways. Within such a multi-theoretical perspective, the *theory of associative autopoietic digital ecosystems* is another social metaphor proceeding from the natural sciences that can be shared by the members of different disciplines to understand and manage social projects and processes associated to the new emerging ICTs identified as grid, e-science, p2p, etc. Starting from biological metaphors the project is very rich in its discussion of complexity. As such it has an ambitious aim of developing theory and articulating it to the analysis of practice. The choice of theoretical framework already frames the theoretical-methodological and action perspective from which the multidisciplinary community participating in the Project makes its reflection and acts.

With regard to the aim of the project –"to enhance the productivity, growth, prosperity and social, cultural and economic balance and sustainability"- it seems to be centered on the approach to development typical of the nineties, in terms of metaphors oriented to the liberal or neoliberal economy, which have been questioned in this decade in several quarters.

The digital economy for the knowledge society is no other than the neoliberal economy that became hegemonic at the beginning of the century and that Europe and its programs toward the knowledge society promoted through ITU to the world, and in the Latin American case through ALICE-CLARA and ALFA. The telecommunication frame is the neoliberal model of telecommunications as described in the e-Europe plan. The scope and limitations of this model derive from its being oriented towards the particular vision of economy and development characteristic of the European Union groups concentrated in the Lisbon Treaty.

Maybe the normative and ethical framework chosen weakens the proposal for it leaves no space to other economic alternatives under construction, for example in Latin America, despite their operational deficiencies, which guides a different ecology of changes or reorganization among actors, institutions, legislation, norms, and practices.

Thinking of its possible applicability in other regional spaces maybe a different more generic category could be used that does not frame the issue solely in terms of the business aspect, as could be that of distribution or exchange. In fact part of the ideology of the open source and open knowledge projects lies in the fact that they are not explicitly interested only in business, but on the contrary seem to address the development model in which business is not restricted to free exchanges among agents.

The theoretical analysis seems to be well grounded and covers a good portion of the relevant literature. In a rapid bird's view reading, which is what we could do at this time, however, there seems to be too great a distance between the idea of the grand theory and its concern for application, reflected in the way the theoretical analysis is counterpoised to what is done in social informatics, which tends to study processes in delimited historical contexts.

Although it is announced in the text that in the project different theoretical approaches are combined to build its own, there are several points in which this mix seems unsatisfactory. For example, the differences between Luhmann and Foucault's conceptions of power are summarized with the help of Rempel. Many differences between the two theories are pointed out in the text. Nevertheless, the quick conclusion is (p. 14, paragraph 4) that both Luhmann and Foucault theorise the relationship between knowledge and language. And this is considered sufficient for the combination. Later, in chapter 4 –"Integrating Biological and Social Science Perspectives" a similar combination is made, this time of Luhmann and Giddens. Because the human actor is not in Luhmann due to his a-historical approach, you add it on by getting hold of Giddens and his structuration theory. We are not very knowledgeable about this but it makes us a bit uncomfortable in several respects, in particular in terms of its implications, for example in connection with WSIS. In part the argument used resounds as the notion of the self regulation of the markets, which from a peripheral position as ours sounds so insincere.

We too are working in the articulation of different disciplines. While you use them to build autopoietic models (biological sciences, computer science and social sciences), we have taken information sciences, computer science and social science for our exploration. But we are not even close to the level of richness and complexity of the analysis you are engaged in of theorizing about the field and its practical applications, and have learnt a lot from reading the report. What strikes us as a bit curious is when this theorization is expressed in a very European fashion in an ethnocentric style, although aware of its western nature.

In chapter 3 "A Binary Meta-Epistemological Framework for Digital Ecosystems", when discussing structuralist social theories, which are identified with marxism, the argument touches only on collectivism vs. individualism, but does not consider, precisely, the understanding of the dialectics as paradigm of the social, as opposed to positivism. Other critical proposals are suggested by the epistemology of social movements, which some authors use for understanding free software.

Taking a cue from biological evolution, a digital ecosystem could be defined, from the point of view of the digital technology, as an environment in which the recombination of the software's elemental components enables a better balance between legacy and innovation. This is correct, but it is a socio-technical choice. The opposite could occur and generate negative behaviors or patterns in socio-technical organizational change. What seems very interesting is the fact that it is an effort to explain the encounter of the metaphor in two disciplines in the context of emergent computing or grid.

The development of software for free software did not depend on a balance between the legal and innovation, it was the explicit confrontation as social

movement between two development positions of software development, the proprietary one and the free one with its greys such as open source.

In 5.2 Social spaces of formal systems is an interesting aspect to explore further. There are other possibilities to consider, such as groupmatic and cases with no clear pattern

It might be interesting to use this perspective to make case studies and see its strengths and weaknessees according to the cases. However, in the formulation there seems to remain the same sociological determinism of the early readings of the knowledge society, technocentric and uniformizing, ahistorical if you like, of cultures. It would be interesting to see how this development model functions in different social contexts, even with the same WSIS agenda, not only in business, but in the ongoing education, health, cooperatives and those technologically based experiences of social production. It would be interesting to see what developments take place in government policies that support the development of free software.

Punctual typing observations:

p.4, final line: how **do** I make one

p.32, first paragraph after heading. Lines 3 and 4, “guide” is repeated, making the construction of the phrase inelegant.

p. 38. line 7. the first time “structures” are mentioned in this line should not be rather “agents” or something like that?

p. 50. Line 4 after the heading. Rephrase “In autopoiesis happens”…. Also the autopoiesis notion remained far behind in the treatment throughout. In the sections that followed the initial treatment of it, it is not mentioned.

p. 50, paragraph 4, first line. One of the most fruitful **outcomes** of the DEAL experiment

p. 50, paragraph 4, last line of the paragraph. That such system can **be** self organizing

p. 54, line 4. selection of **applicable** research methods

p. 60, line 2 after Figure 6.2. with the specific aim of **being** adaptable

In the Quality check box at the beginning of the report, where you mention the Internal reviewers, you do not need to mention us, but if you wish to, in both cases you should simply mention our institutional affiliation, Venezuelan Institute of Scientific Research.

OPAALS Project IST-034824

WP12 - D12.10

Internal Review: Prof. Joe Wallmannsberger, University of Kassel

7 July, Internal Review Memo

0.
The deliverable under review clearly presents a major step in the development of an advanced foundational framework for the project, critically reconstructing both metatheoretical options and systems desing principles; there can be no doubt that the treatment as is meets the relevant criteria of a network of excellence deliverable, so it is my pleasure and priviledge to recommend adoption of the paper, with the appropriate elaborations and extensions marked as forthcoming in the text itself.
The following remarks reflect my continued engagement with the intellectually challenging discussion in this presentation, pointing to opportunities for further work specifically in the more strictly foundational aspects of the analysis proposed here. It would seem advisable at this point in time not to attempt the integration of these echos and responses into this particular deviverable, but rather to let these precipitates develop into the joint enterprise of what may come to be called a future Tractatus logico-opaalicus.

1.
The dynamics of the form/function interface must be captured by the most advanced conceptual tools available, so one may profit from integrating "dynamic logics, "game logics" and "network coding logics" perspectives into the overall model to be constructed. The work of Rohit Parikh would seem to offer real potential in capturing the dialectics between logical updating-mechanisms and self-organising, para-biological systems, most notably his "logic as social software"-approach. From a computational linguistics point of view, the connection with recent work by Benthem (Amsterdam and Stanford) and van Eijck (Utrecht) would seem to be very suggestive indeed. The real treat (and trick, in a way) is for these models to take a dynamic approach right to the of logico-algebraic systems, hitherto taken to represent the discrete/static spectrum of formal sytems, as opposed to the inherently dynamic algorithms in the analytic/calculus-driven domains.

2.
The move from static representations to real-world dynamic systems is particularly noticeable in the dynamic logic work of Moshe Vardy and his confreres, culminating in paradigms of "industrial logics" employed in the desing and verification of large scale intelligent systems.

3.
A network-driven conceptual space such as OPAALS would clearly benefit from employing the exciting new coordinates offered by recent work in the "network coding"-community (based on original work by Ahlswede, Li and Yeung), taking as their point of departure the radical insight that communications networks may be working optimally when they start "inventing" the messages to be conveyed, the advent of the "story generating router," as it were.