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THE (IM)POSSIBILITY OF INTERDISCIPLINARITY: LESSONS FROM CONSTRUCTING A THEORETICAL FRAMEWORK FOR DIGITAL ECOSYSTEMS

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Abstract

This paper reflects critically on challenges and opportunities associated with developing a theoretical framework for an interdisciplinary Framework Programme 7 research project funded by the European Commission in the area of digital ecosystems. The paper first provides a description of the interdisciplinary structure of the research agenda of the project and the areas of digital ecosystem research prioritised by each discipline. Second, it discusses the challenging questions of epistemology that arose in the context of theorising interdisciplinary research and provides a summary of how these were dealt with in order to outline a theoretical framework for digital ecosystems research by the end of the project. Finally, it discusses the lessons that can be extrapolated from the project experience, arguing that it is *impossible* to develop a unified interdisciplinary theoretical framework due to irreconcilable epistemological differences, yet it is *possible* and very worthwhile for those adhering to various disciplinary perspectives to collaborate towards the achievement of a practical joint endeavour. These lessons, which are considered valuable to the broader research community, are summarised in a model of the (im)possibility of interdisciplinarity.

Keywords: digital ecosystems, interdisciplinary, epistemology

Table of Contents

1

This paper reflects critically on challenges and opportunities associated with developing a theoretical framework for an interdisciplinary research project titled OPAALS (Open Philosophies for Associative Autopoietic Digital Ecosystems), a Framework Programme 7 Network of Excellence funded by the European Commission (EC) from 2006 to 2010. The four-year €9.1 million project was comprised of a consortium of 20 partners from across the world and was led by the London School of Economics and Political Science. Its overarching research aim was to develop a theoretical foundation for 'digital ecosystems' research.

The community of projects and researchers that emerged around the concept of digital ecosystems (DEs), introduced by the EC in 2002 (Nachira 2002), consistently held the view that DEs have the potential to become a significant part of the next generation of information and communication technology (ICT) and Internet usage.[1] Although applicable in many contexts, from the perspective of OPAALS researchers, DEs may have the greatest potential in enabling small and medium-sized enterprises (SMEs) to compete on the global stage. Based on open, peer-to-peer architectures and open source software (OSS), digital ecosystems integrate trends in the technical, social, and economic aspects of the networked world. As well as pursuing the development of the science and technology features of digital ecosystems, the OPAALS project integrated a focus on the social, cultural and policy implications of this new mode of organising distributed architectures and online environments for collaborative research into its research agenda.

As is evident from this brief description of the research aims of OPAALS, a variety of disciplinary perspectives and scientific methods was required to work towards and partly reach these ends. The project consortium was comprised of experts from disciplines as diverse as biology (from which the metaphor of the ecosystem originates), mathematics, physics, engineering, the social sciences (including media and communications, information systems, management, sociology, and some branches of economics), linguistics and, of course, computer science. The ethos of interdisciplinarity and the pragmatism of multi-disciplinarity were thus present from the very origins of the project, as reflected in the multi-faceted definitions shown in Table 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

Table 1: Multiple perspectives on digital ecosystems

Whereas the above table is subjectivist/individualist in character, in that it lists the different ways in which DEs are *perceived* by practitioners belonging to different disciplinary domains, a useful complementary perspective that is objectivist/structuralist in character is one that asks what requirements a socio-technical-economic *system* needs to satisfy to warrant being called a DE. This view suggests several propositions that underpin DE research: 1) ICTs lead to efficiency improvements; 2) sustainable development is best achieved when the social dimension of economic interactions is explicitly taken into account; 3) greater collaboration *within* a particular geographical region or virtual community leads to sustainability of economic growth and enhances the

competitiveness of that region or online community; 4) DEs are best built on an open source infrastructure; and 5) that infrastructure should be distributed.

These propositions are fundamental to DE research in the sense that:

> All foundational systems need ultimately to assume the soundness of their 'axioms' and method of construction. … For knowledge to be possible, there must be some propositions which can be known without proof or evidence. These are [the] foundations of knowledge. (Hollis 1994: 68-69)

In the OPAALS project these starting hypotheses or propositions were foundational in the sense that they motivated the search for a theory that would show how sustainable socio-economic development may be associated with DEs. The exploration of these hypotheses was pursued through theoretical and empirical research over a number of years (e.g. Van Egeraat et al. 2008; Rivera-León et al. forthcoming). In this paper, we are concerned with the process of development of an analytical framework through which practitioners in different disciplines can work together. This process followed an unplanned bottom-up path which required for its full expression an inclusive and safe environment of collaborative enquiry.

Interdisciplinarity was thus neither a normative goal nor naturalised in the project: as part of a reflexive engagement with the work being done to (first) understand, design, and (ultimately) develop digital ecosystems, it was understood that part of that task would entail the development of a theoretical framework that could support the conceptualisation of an interdisciplinary ethos. OPAALS researchers did not take interdisciplinarity for granted. The definition and attainment of research objectives according to each discipline's respective priorities and principles of scholarship was regarded as a necessary step preceding any attempt at interdisciplinary integration. Integration was seen as a *potential* outcome of a bottom-up process of balancing between respecting disparate epistemological perspectives and recognising opportunities for new syntheses.

Before proceeding further, what we mean by 'integration' needs to be understood. If 'unification' is understood to imply considering two or more apparently unrelated phenomena within the same theory or model, then 'integration' is understood here to enable different theories to coexist with a degree of compatibility that does not imply that the same theoretical foundation underpins them. An example of the former is electricity and magnetism which were thought to be different physical phenomena until a single set of equations was derived by Maxwell (1873). An example of the latter is the understanding of computers as media of communications, rooted ultimately in Heidegger's phenomenology, sitting side-by-side with the understanding of computers as machines operating on objective data and whose functions can be optimised (Winograd and Flores 1987). The experience of the OPAALS projects suggests the greater feasibility of integrating rather than unifying different disciplines.

The OPAALS project aimed, in part, to interrogate the strengths and weaknesses of interdisciplinary perspectives. In this paper, we explain the elements of the theoretical framework developed for understanding DEs and what was learned about the feasibility of this approach.[2] To develop this explanation we draw insights particularly from theories concerned with communication processes and power relationships. Our understanding of interdisciplinary integration evokes a longstanding observation in the field of communication research:

> We sometimes forget that communication research is a field, not a discipline. In the study of man, it is one of the great crossroads where many pass but few tarry. Scholars come into it from their own disciplines, bringing valuable tools and insights, and later go back, like Lasswell, to the more central concerns of their disciplines. (Schramm 1959, in Berelson 1959)

As suggested by this quotation, there are many difficulties in communicating across disciplinary boundaries which are attributable in part to the plurality of voices that have an 'inhibiting effect' on the construction of 'global, totalitarian theories' (Foucault 1980: 80), a theme that we return to later in this paper.

Although we discuss certain epistemological questions in some depth, we do so unevenly, privileging social science over the epistemologies of mathematics, biology, computer science, or physics. Our main objective is to report on the learning process which led us to contend with epistemological questions while addressing the challenges of interdisciplinary collaboration, rather than to develop an extensive discussion of the epistemology of science. Learning theory (e.g. Vygotsky 1978) has been used in analysing the process of ICT development (Millar 1996). However, in this paper the principal concern is with the lessons learned specifically from our critical reflection on the experience of engaging with inter-epistemological challenges.

The paper is organised as follows. First, we provide a description of the areas of DE research prioritised by each of the disciplines involved in the OPAALS project. Second, we reflect on challenging questions of epistemology that arose in the context of developing interdisciplinary research and offer a summary of how these were dealt with in order to outline a theoretical framework for understanding DEs by the end of the project. Finally, we outline some of the outcomes of the work undertaken in the project and discuss the lessons from this experience. We argue that while it is *impossible* to develop a unified interdisciplinary theoretical framework due to irreconcilable epistemological differences, it is *possible and worthwhile* for those adhering to various disciplinary perspectives to work together to contribute to the achievement of a practical joint endeavour, a lesson with broader relevance to other interdisciplinary research communities.

OPAALS'S INTERDISCIPLINARITY

The development of a theoretical foundation for understanding DEs from the outset of the OPAALS project was conceptualised as a problem requiring an interdisciplinary solution, partly because of the multiple possible meanings ascribed to the term 'ecosystem'. The concept of the 'business ecosystem' (Moore, 1996), uses 'ecosystem' as a *metaphor* to capture the dynamic interactions between socio-economic agents and actors. The presence of the word 'digital' in 'digital ecosystem', however, opens the possibility of interpreting 'ecosystem' as a *model* that can serve as inspiration for the development of software systems that self-organise and for software services and applications that emerge spontaneously from an artificial life-like environment. We refer to the field that studies the latter as biologically-inspired computing, or bio-computing.

Domains and territories

One of the central research goals of OPAALS was to build an interdisciplinary community that would enable those adhering to various disciplines to engage with research questions related to DEs from their respective points of view. The work of OPAALS entailed the encouragement of a spontaneous convergence of these perspectives over time partly through the development of a common language aimed at solving shared research problems (Dini et al. 2008a: 9). This required communication strategies to support and underpin interdisciplinary collaboration as well as an acknowledgement of a discursive view of knowledge construction. From a discursive perspective, knowledge is conceptualised as emerging from scientific practice which is, in turn, shaped by political, social, cultural and disciplinary pressures. Scientific discourses are understood as practises 'that systematically form the objects of which they speak' (Foucault 1969: 54). The disciplinary scientific discourses engaged in the project of constructing knowledge about DEs produce such knowledge through their practices of research. In this sense, knowledge can be conceptualised as discursively self-forming or evolving over time, a process which takes shape in language (Dini et al. 2009: 13). This understanding was most evident within the social science domains of the project, although (as will be discussed) it became increasingly evident in the natural and computer science domains as the research progressed.

The interaction of the natural science, computer science and social science disciplines in OPAALS research is visualised in Figure 1, which was created at the beginning of the project and played an important role in fostering the structure of interdisciplinary interactions from the outset.
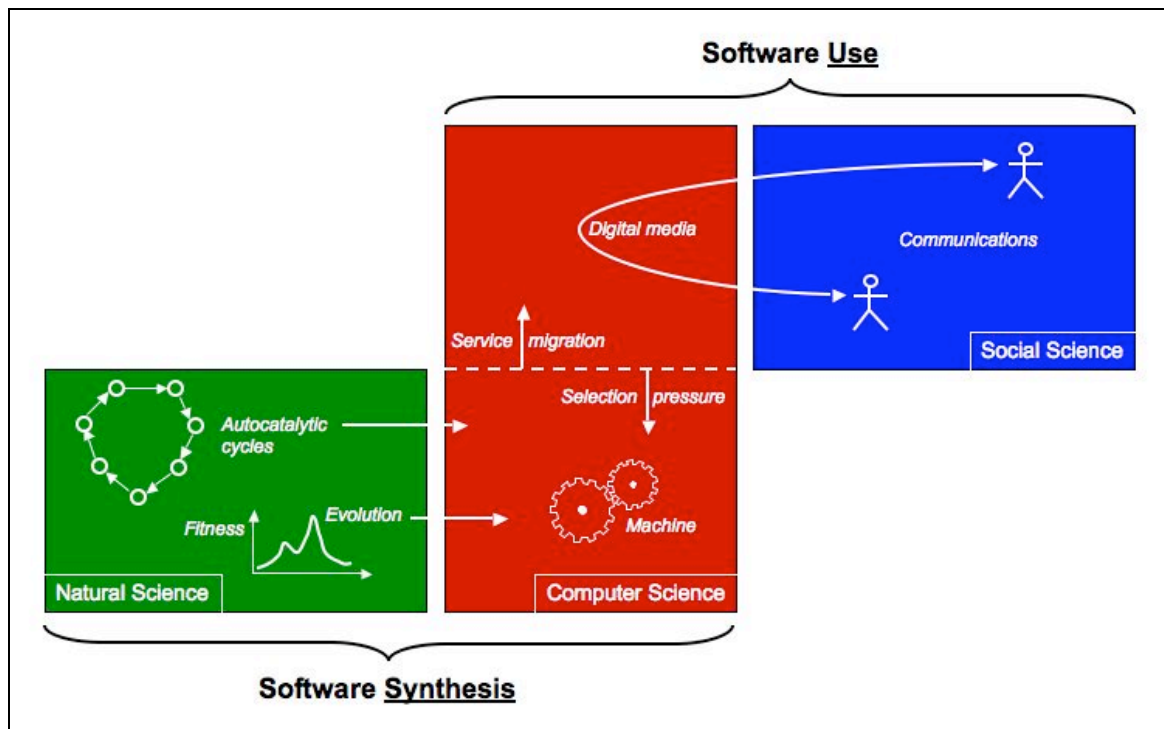

Figure 1: Interdisciplinary structure of OPAALS research

The central position in this figure of computer science is due to the fact that computers can be seen from two ontological points of view.[3] The first and older conception sees computers as machines that are understood through a functionalist epistemology in which the optimisation of performance is the main focus. The second, now more widely accepted, view sees computers as media of communication that are integrated into the social (Winograd and Flores 1987). The functionalist perspective is appropriate for the research agenda in bio-computing, whereas the interpretation of computers as media of communication fits better with a social perspective on socio-economic agency, which informed part of the project's epistemology. The applied computer science domain was positioned at the interface of the social and natural science domains within the OPAALS project. The objectives of each domain's approach to DE research are summarised next.

<u>Natural Science</u>

From a natural science perspective, the research agenda of OPAALS was tied to the fundamental question of whether a biological ecosystem could be used as a model for the development of a software architecture that could sustain the self-organisation of software artefacts.

> This research question is premised on the assumption that such biological properties can increase the effectiveness of information and communication technologies (ICTs) in various application domains, from ubiquitous computing, to autonomic communications, to socio-economic processes aimed at regional development, simply on the basis of their greater and spontaneous adaptability to user needs (Dini and Schreckling 2010).

This question had been answered in the affirmative by an OPAALS forerunner, the Digital Business

Ecosystem (DBE) project, in the form of a distributed evolutionary environment whose architecture was defined and partly implemented during the course of that project (Briscoe and DeWilde 2005; Heistracher et al. 2006). Another outcome of the DBE project, however, was the realisation that an evolutionary environment was not sufficient to achieve ecosystemic behaviour in software, a conclusion that is echoed by some biologists. As discussed by Kauffman (1993), for example, evolution is not sufficient to explain the very powerful order construction processes and phenomena observed in nature. Evolution constructs order through mutation, sexual mixing, and selection of hereditary traits across many generations and over very long periods of time, a process called phylogeny. The complement of evolutionary processes is embodied in cell metabolic processes, which construct order through biochemical interactions within the life of the individual organism, a process called ontogeny. The 'hinge' that connects phylogeny to ontogeny is the DNA molecule.[4]

For this reason the natural scientists and mathematicians in the project consortium felt it was important to build a strong component of cell biology research into OPAALS and principally for this reason adopted autopoiesis (Maturana and Varela 1980, 1998) as a catch-all concept for representing processes by which systems, like the biological cell and, in particular, stem cells, can reproduce themselves with the recursive ability to reproduce themselves being built into their blueprint.

Natural science DE research can be considered functionalist in that its aim is to improve the performance properties of the software. This is an area that requires further research to achieve these goals, although OPAALS's development of a theoretical framework for bio-computing (Dini and Schreckling 2010) connecting cell metabolism to algebraic automata theory and to specification languages through category theory, introducing the concept of Interaction Computing, contributed to this outcome.

Computer Science

Computer science DE research addresses many facets of distributed software systems[5] and of formal/business modelling languages.[6] Insofar as technology embodies cultural values (Feenberg 1991, 2002) this calls for the assumption of responsibility on the part of technologists. The computer scientists of the DE community therefore elected to approach, and largely embrace, a normative requirement of distributing every aspect of the architecture. A distributed architecture avoids single points of failure, which is a functionalist value, but also single points of control, and therefore is more consistent with a goal of encouraging competitive, rather than monopoly supply of services.

The realisation of distributed architectures for all aspects of the software system was a huge challenge for OPAALS due to the need to reconcile two opposing requirements (Dini et al. 2008b; Razavi et al. 2009). On the one hand, the (normative) requirement was to avoid single points of control and the (engineering) requirement was to avoid single points of failure. This called for a 'pure' peer-to-peer architecture which is very inefficient for data and message propagation. On the other hand, the (functionalist) requirement for efficient data and message propagation called for a hierarchical network, based on so-called 'super-peers' and this would violate the first requirement.

The solution was the concept of *dynamic*, *virtual* super-peers (DVSP): 'virtual' means that each super-peer is actually a collection of machines, whereas 'dynamic' refers to the fact that membership in the cluster of virtual super-peer machines is dependent on the resource availability of the participating peers. Furthermore, the owners of the servers do not know at what level in the hierarchy the machines are at any one point, and cannot, therefore, take advantage of their machine's privileged position when it is at the top.

The structure and configuration of this hierarchical and dynamic P2P network is also dependent on the requirements for transaction robustness and recovery in the transaction model. The execution of a complex service that involves many individual web services located on different machines and at different locations requires a transaction coordinator that can orchestrate the handover of the data from

one service to the next, provide roll-back recovery in case of a failed step in the transaction, and generally ensure smooth and reliable operation of the overall service. In most web service scenarios, this function is provided by a transaction coordination service running on a centralised transaction server. In order to guarantee roll-back recovery, such servers require the participating companies to expose the details of their business processes, which are stored on the central server (each state of the transaction is stored, leading to a 'stateful' model). This creates an asymmetry of information about the market which the owner of the transaction server can then exploit.

To offset this 'market failure' problem, the University of Surrey developed a distributed coordination service (Virtual Private Transaction Network, VPTN) that eliminates the central server completely. The distributed coordinator is composed of software agents that travel to the service end-points, request data from the relevant service through an agreed interface, and ensure local consistency of execution. If a transaction step fails, the execution is rolled back to the previous *step* (not state) and the necessary data is requested again through the agreed interfaces (thus this model is called 'stateless').

This P2P infrastructure was completed with a distributed identity model which does not rely on Domain Name Servers (DNS) (McLaughlin and Malone, 2010). From the point of view of identity, in fact, the DNS system can be regarded as a central point of control. Rather than being mapped to web Universal Resource Locators (URLs) or Universal Resource Identifiers (URIs), the Internet Protocol (IP) addresses of a P2P digital ecosystem are mapped to personal identifiers that are known only within the network itself. As a consequence, a P2P DE is 'invisible' to the regular web, to search engines, etc.

Social Science

From a social science perspective, DE research asked: what are the social, political and cultural processes required in order to achieve sustainable socio-economic development enabled by the science and technology? The social science element of DE research was based on an understanding of the relationship between *bottom-up processes* and the *structural principles* of socio-economic action. DE research entailed an engagement with questions of language, communication and community building at both the level of the individual and the collective, as well as an assessment of various social, economic and political (in terms of community governance and policy implications) elements of the establishment of DEs.

In this context, issues were highlighted regarding the policy perspective on DE adoption on the regional scale as well as areas of theoretical debate that opened up from there, culminating in the 'primary' concepts of open knowledge, power, control, and democratic process. These informed the design principles for the DE architecture explained above (no single point of control/failure, diversity, reliability, distribution), leading to what we argue was a satisfactory integration of the computer and social science domains at both theoretical and practical levels (Moschoyiannis et al. 2008). Indeed, as Crone and Bräuer (2007) discuss, research relating to ICT and socio-economic change is interdisciplinary by its very nature. In OPAALS, it was argued that technological and social issues involved in providing the necessary digital infrastructure should not be treated as distinct issues but instead as part of the same continuum (Moschoyiannis et al. 2008).

The dialogue between the two domains enabled the project to 'process' the top-down, normative requirements insisted upon by the European Commission that every aspect of the architecture had to be distributed and that all software had to be Open Source. That is, to protect the integrity of scientific research it was important to re-examine independently these normative requirements. The result of the exercise was an informed decision to embrace the architectural criteria and Open Source properties of software as starting assumptions for the project.

With multiple disciplinary perspectives on the process of defining DEs, it was clear that it would be

necessary to work towards a theoretical framework that could hold all of these perspectives, but the achievement of this objective was fraught with difficulties. For example, whereas a satisfactory level of integration was achieved between computer science and social science, and very interesting possibilities emerged for the integration and even unification of computer science and natural science, the integration of social science and natural science remained problematic, as we now explain.

QUESTIONS OF EPISTEMOLOGY

The above disparate research agendas suggest that a great deal of work would be required in terms of conceptualising and theorising interdisciplinary research and in actually doing it. Constant challenges arose in enabling very different, and often completely incompatible, epistemologies and theoretical traditions to engage with one another and to coexist within a theoretical framework that needed to be applicable to the entire project.[7] Issues of communication among researchers were a key priority – but understanding was not possible unless epistemological differences could be acknowledged. Similar challenges were experienced in DE research that pre-dated the OPAALS project. For example, in the context of the DBE project, Dini and Berdou (2004) argued that in order for dialogue to take place between the domains of social science and natural science, multiple approaches and agendas needed to be acknowledged, certain barriers needed to be lifted and certain links needed to be made explicit. This was not to suggest that epistemological and ontological questions needed to be settled in order for interdisciplinary cooperation to take place, but it did imply that these differences would need to be taken seriously in the successor project, OPAALS.

An interesting example of the problems of epistemology concerned the concept of autopoiesis, which appears in the title of the research project. The inclusion of the term was rooted in the research agenda of bio-computing, and inspired by the cognitive science developed by Maturana and Varela (1980, 1998). The term also held appeal for social scientists as its relativist basis resonated with some aspects of phenomenology and social constructivism perspectives:

> Maturana's work represents a distinct advance on classical phenomenology, a major criticism of which is that it is essentially individualist and has great difficulty in generating the intersubjective nature of social reality. Here Maturana begins from an intersubjective position. We are (as self-conscious beings) constituted through our language, and language is inevitably an intersubjective phenomenon. As Wittgenstein also argued, there can be no such thing as a private language. Thus language is essentially a consensual domain of agreements, of structural coupling that permits the operations of observers. (Mingers 1995: 110)

Similarly, one of the core debates that characterised interdisciplinary research and dialogue within the OPAALS consortium from its inception was the relationship between agency and structure, that is, the role of individual actors within a social scene and the collectively defined and managed structures of these roles. Epistemological differences – are social systems constructed only through communication, by human agency, language and action, or through relations of production? – were evident in the project from the outset:

> We have come to the realisation that the main challenge of the OPAALS project is not so much that it is a deeply interdisciplinary research project but, more fundamentally, that it is an *inter-epistemological* research project—and that it seeks to find constructive integrative solutions at theoretical and applied levels that are relevant and useful to associative autopoietic digital ecosystems (Botto et al. 2008: 6).

The concept of autopoiesis has links to social systems theory, especially as developed by Luhmann (1995), who argued that social systems are built from recursive communications. This perspective excises agency and individual hermeneutics and this was problematic for some social scientists working in OPAALS. A possible solution was to add, at the proposal stage, the term 'associative' in the title of OPAALS, before 'autopoietic', as a means of complementing and balancing the 'autopoietic' viewpoint by making the role of the individual social actor as explicitly central to the project as a systemic conceptualisation of DEs.

Differing epistemologies are most evident when comparing, for example, natural science and social science, but they are also evident within the social sciences. A 'map of social science' proposed by Hollis (1994) was used within the project to summarise the main analytical traditions in the social sciences divided along two axes: the first a commitment to objectivism or subjectivism, the second a commitment to structure or agency. As shown in Figure 2, the blue boxes indicate some of the social science epistemologies that the project encompassed.
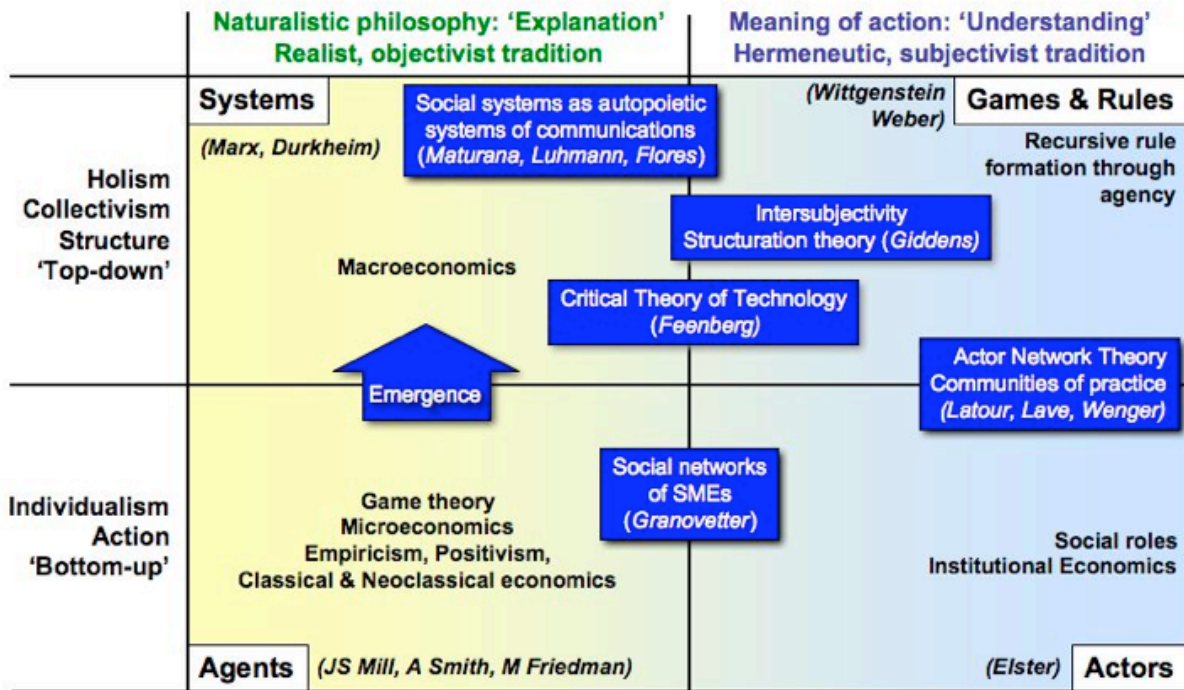

Figure 2: Map of social science (adapted from Hollis 1994)

A few indicative names are shown to make the table easier to interpret. The left-hand column is generally associated with the rationalist, deterministic tradition. It is the older of the two, and grew out of naturalistic philosophy. The right-hand column is more recent, reflecting a greater emphasis on the social world in defining reality (ontology) and the construction of knowledge (epistemology). Although interpreting the two columns as an objective-subjective dichotomy risks gross oversimplification, those in the left-hand column can be grouped loosely as sharing a belief in some form of 'objective' reality, whereas a more 'subjective' perspective permeates the ideas of those named in the right column. The column on the left is generally acknowledged to have a much greater constituency (and to attract more funding) within social science than the traditions on the right that are inspired in part by a hermeneutic philosophy The table can also be understood in terms of different accounts of social systems and human action. The top row favours a view of society and the economy that is biased toward the importance of structures and systems over individuals, whereas the bottom row represents the opposite emphasis. This distinction is reflected in methodology in the sense that theories in the top row tend to be deductive, deriving behaviour from general principles, whereas the bottom row is associated with the tradition of empiricism and positivism, where general principles are derived from experience through an inductive process.

During the course of the OPAALS project this map helped researchers to see that the task of developing a theoretical framework for DE research was necessarily rooted in the social sciences, as neither computer nor natural science embrace an epistemology that enables researchers to reflect critically on their own ontology and epistemology, without recourse to some discipline within the

social sciences or humanities. A notable exception is the second-order cybernetics movement, and autopoiesis itself, which acknowledged the role of the observer as part of the system being observed (Brand 1976). However, the system perspective that predominates in these movements, as well as in the more recent complexity science, makes them difficult to relate to associative and individualistic understandings of society.

A drawback of this map is that it seems to conflate 'structuralism' and 'collectivism'. Structuralism views the relations of production as providing a structure within which individuals move and live their lives. When the relations of production take the form of capitalist institutions, the individual may appear to become a powerless pawn that can only move along corresponding predefined paths. The way to counter structural forces and constraints is for individuals to form larger groups that can balance the weight of institutions: for example, labour unions. Collectivism can be understood as a human *response* to socio-economic structure. Therefore, although closely associated with structuralism, collectivism is not synonymous with it. As discussed, for example, by Siedentop (2000) the individualism/collectivism dichotomy is also associated with the discourse of modernity, which adds another element of potential confusion.

A central aspect of the modernity discourse is the issue of individual freedom vs. allegiance to the group (be it family, tribe, city, or nation. For example, countries like Italy can be seen to be in the middle of a transition from a 'pre-individualist society' (Siedentop 2000: 166-7), where the individual owes allegiance to his/her family before him/herself, to a society where the individual asserts his/her right to individual freedom. Of course the Western discourse of modernity has been amply criticised by e.g. postmodernist philosophers (Lyotard 1979) as being deaf to other paths of cultural evolution and self-discovery. The point here is that both with respect to individualism and collectivism, the modernity debate has been appropriated by political currents that are concerned mainly with questions of socio-economic action. This has contributed to further polarisation. For example, individual freedom has been applied to economic action, becoming the cornerstone of neo-liberalism. By contrast, collectivism can be taken as the starting point for new value systems based on social capital, collaboration, and public goods theory, which underpin some of the DE propositions in the introduction to this paper. For historical reasons that we cannot consider here, collectivism is also associated with socialism, communism and fascism. These conflations caused a significant amount of internal tension within the project as we strived for consistency with the OPAALS project's initial assumptions and for their validation.

In addition to the challenge of defining a theoretical framework that could accommodate different disciplinary viewpoints, we also faced another in that the European Commission had asked explicitly for the project to develop a *unified theory* of digital ecosystems. A constructive way to respond was provided ultimately be proposing a *meta*-theoretical framework (Dini et al. 2008b; Botto et al. 2008; Dini et al. 2009). Although (predictably) falling short of the unification called for, this embraced all the theoretical and disciplinary viewpoints encompassed by the project. The meta-theoretical framework addresses a wide range of themes, fields, and theoretical currents within and outside social science which cannot be mapped easily onto the 'associative' and 'autopoietic' dichotomy in the title of the OPAALS project. This is not surprising since the work of the project transcended its initial conceptualisation. In the process of responding to these challenges, an appreciation of the implications of Foucault's analyses of power relations was fostered. In the next section we discuss the meta-theoretical framework and, in the one following, we address aspects of the power relations that the reflexive element of our research helped to uncover.

<u>A binary meta-epistemological framework</u>

It was necessary to develop a way of working with the variety of epistemological positions underlying each of the disciplinary research agendas described above. The solution devised was to identify the epistemological tensions within OPAALS's DE research and to acknowledge them rather than to gloss over them. Table 2 summarises four key axes of epistemological tension, the key 'big questions' in

relation to DE research, and the theorists invoked in order to examine the complexities and contradictions in depth.[8]

Axis of Debate	Key problematic for DE Research	Theorist
Empiricism vs. Rationalism	Should (natural, computer, social) scientific research be deductive or inductive? Are DE theories falsifiable?	Popper Quine
Objectivism vs. Subjectivism	How do social and technological structures interact with individual agency and interpretation? Can (should) structuralism and socio-constructivism be reconciled?	Popper Gadamer Giddens
Individualism vs. Structuralism/ Collectivism	To what extent can individualistic (market-driven) and collectivist/structuralist (open source, community-oriented, relations of production-dependent) processes be reconciled in DEs?	Giddens
Symmetry vs. Context-dependence	How might the absolute values of the physical sciences translate into situations demanding open-ended evolution?	Holland

Table 2: A summary of OPAALS's meta-epistemological binary framework

With respect to the tenets of objectivism and subjectivism, Karl Popper's (2002) insights on 'objective method' were taken as a reference for the former, and Hans-Georg Gadamer's (1975) philosophy of subjective hermeneutic interpretation was taken as a reference point for the latter. Anthony Giddens's (1984, 1991) work was taken as a reference point in finding a constructive way to reconcile these positions. Next, because in DE research theoretical and metaphysical considerations are mixed with empirical observations and practical applications, it was necessary to acknowledge the presence of useful roles for the tenets of both rationalism and empiricism. Popper's work offered a constructive balance which is compatible with Giddens's work, while Giddens's insights also address, the individualism vs. structuralism debate. For these reasons, Popper and Giddens were utilised to provide a theoretical core around which theoretical constructions in DE research could be justified.[9] We also proposed 'symmetry' and 'context-dependence' as discussed by Holland (1975) and Schreckling and Dini (2009) as 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 aimed 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 was considered appropriate to digital ecosystems (Dini et al. 2009: 25).

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/structuralism in favour of theorising and negotiating the relations of subjectivism and objectivism. In his later works, Giddens (1991b) turns his attention to exploring the notions of self-identity and life politics which take the individual as the focus of social action, and the implications for social theory. His theory of structuration can be understood, however, as a collectivist theory which aims at explaining how communities of social actors contribute to, and are affected by, social structure. Structuration as a concept can be employed to explain socio-economic action at both individual and institutional levels and is helpful in understanding the balance between individualism and structuralism within DE research and within DEs themselves. Structuration is a theory or a designation of a process.

This epistemological framework offers:

- A rationalisation by which candidate theories or extensions to DE theory can be 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 concept, can combine the empirical testing of theories with multi-stakeholder

processes for the phased introduction of digital ecosystems in different regional contexts understood in terms of social-constructivism theories.
- An epistemology based on structuration theory that puts processes of institutionalisation and of technology development on a similar footing, wherein structuralism is balanced by individual action and collective 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 while remaining open to new forms and, hence, is able to interface to human expression and behaviour.

This framework brings together a variety of orthogonal theoretical viewpoints. The intention of suggesting these juxtapositions was not to force these points of view together in order to suggest a new synthesis, but instead to show the necessity of working with and exploring a variety of theoretical viewpoints in order to find creative ways to locate, ontologically and epistemologically, and construct, through the process of reflexive research, a theoretical framework for DEs. The framework is best understood as being indicative of four dimensions of epistemological activity in constant dialogue with each other and facilitated through a network of multi-disciplinary research. To provide an environment for scientific enquiry that would be sufficiently safe for the participants to engage in the pursuit of difficult dialogues, it was also necessary to acknowledge the importance of an additional underlying discussion concerning the emergence of different epistemes and their respective power relationships.

Totalitarian theories and meta-theoretical apparatuses

> It is not possible for power to be exercised without knowledge, it is impossible for knowledge not to engender power. 'Liberate scientific research from the demands of monopoly capitalism': maybe it's a good slogan, but it will never be more than a slogan. (Foucault 1980: 52)[10]

The research conducted in OPAALS was intended to be responsive to the European Commission's request for a 'Science of Digital Ecosystems'. Our response was to highlight an inconsistency between a normative request to distribute every aspect of the architecture (see above discussion) and a demand for the development of an 'exclusive' science. Foucault's characterisation of a larger problematic fits well with the dilemma encountered by the project:

> What types of knowledge do you want to disqualify in the very instant of your demand: 'It is a science'? … Which theoretical-political avant garde do you want to enthrone in order to isolate it from all the discontinuous forms of knowledge that circulate about it? … in contrast to the various projects which aim to inscribe knowledges in the hierarchical order of power associated with science, a genealogy should be seen as a kind of attempt to emancipate historical knowledges from that subjection, to render them, that is, capable of opposition and of struggle against the coercion of a theoretical, unitary, formal and scientific discourse. (Ibid.: 85)

Following Foucault's insistence on a genealogy of knowledge which emancipates disciplines to develop and to struggle against the 'the tyranny of globalising discourses' (Ibid.: 83) exemplified by the enthroning of a single avant garde theory such as the notion of a unified 'Science of Digital Ecosystems', the OPAALS researchers sought to ensure that the insights drawn from different disciplines were drawn upon in a way that valued their respective contributions.

In contrast to the top-down directive emanating from the hierarchy of the Commission, the researchers' experience of the project hinted at the possibility of a *system of ideas* which can be related to Luhmann's autopoietic system of communications (Dini et al. 2009: 68) in the sense that he argues that social systems are built from recursive communications. This experience was also resonant with Foucault's understanding of the 'apparatus' of a given system of relations of power:

> … a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, moral and

philanthropic propositions – in short, the said as much as the unsaid. Such are the elements of the apparatus. The apparatus itself is the system of relations that can be established between these elements. … The apparatus is thus always inscribed in a play of power, but it is also always linked to certain coordinates of knowledge which issue from it but, to an equal degree, condition it. This is what the apparatus consists in: strategies of relations of forces supporting, and supported by, types of knowledge. (Ibid.: 195, 196)

In his discussion of the 'apparatus' of knowledge, Foucault distinguishes between the strategies of relations of the forces of knowledge creation and the episteme or types of knowledge. This is relevant to our discussion of the search for an interdisciplinary epistemology because these distinctions help to reveal what procedures and ideas come to be accorded scientific status and which do not.

The episteme is the 'apparatus' which makes possible the separation, not of the true from the false, but of what may from what may not be characterised as scientific. (Ibid.: 197)

In his discussion, Foucault is referring to the status of knowledge in the context of a particular discipline or epistemology.[11] In the OPAALS project, we encountered the need for a 'society of disciplines' or a 'society of epistemologies' and, hence, the idea of the 'apparatus' of knowledge offered a helpful starting point. The further development of these ideas could not be pursued within the project itself. Nevertheless, with these observations, we have the conceptual references to offer a more detailed discussion of what emerged as possible and impossible with respect to the interdisciplinarity inquiry into and understanding of DEs.

THE (IM)POSSIBILITY OF INTERDISCIPLINARITY

In a research area such as DEs, which is defined by its interdisciplinary collaboration and a wide array of theoretical and applied expertise, the theoretical framework itself needs to be complex and open to adaptation and evolution as the research progresses and its boundaries shift. It needs to be both 'inter-disciplinary' and 'inter-epistemological'. The experiences of approaching the DE challenges from a variety of disciplinary perspectives allowed some valuable lessons to be learned.

Working with apparently irreconcilable epistemologies at times simply involved acknowledging contradiction. For example, in relation to the divide between socio-constructivism and objectivist perspectives on DE technology, it was clear that both perspectives have relevance and importance. It was important to acknowledge that socio-constructivism is not necessarily anti-objectivist and that it cannot be extended to discuss 'absolutely everything' (Boghossian 2001). In DE research, social constructivism can be very useful in illuminating some aspects of socio-economic action particularly with respect to socio-economic development processes, but this does not mean that objectivist perspectives must be abandoned since these are easier to relate to quantitative indicators, empirical data, and pragmatic policy discussions.

Ultimately, OPAALS research highlighted a key point about interdisciplinary collaboration, alluded to in Figure 1: namely, that social science perspectives are best suited for understanding the values embedded through technology (software) *use*, whereas the bio-computing perspective may, if eventually successful, make it possible to *synthesise* software automatically. Between these two modes of relating to software technology sits a third, i.e. software *design/creation*. Since software design and/or creation is the human expression of a technical artefact represented as a formal language that is subject to mathematical laws or constraints, it appears to serve as the nexus of different 'epistemological currents'.[12] This interplay between objectivist (integrated natural and computer science) perspectives and subjectivist (hermeneutic and socio-constructivist) perspectives is graphically represented in Figure 3. This figure can also be seen as a first attempt at conceptualising an 'apparatus' for the knowledge society.

This figure is rooted in the engineering practice of using schemata to formalise and communicate the structural and functional architecture of systems. When the systems in question involve social actors

such schemata cannot help but appear to be reductionist, requiring complementary argumentation and explanation. The figure schematically depicts important sociological arguments about the ways in which ICTs are integrated in the social life of their users (see e.g. Bell 1979; Castells 1996, 2003; Webster 2006; Mansell 2010). Figure 3 proposes that this can be explained through a virtual circle or a closed and self-reinforcing cycle that links ICT production to ICT consumption through feedbacks that are tighter than is observed for older, physical technologies. Starting with the development of software, i.e. of the *medium*, a case can be made for a 'reverse compilation' process that can in principle transform electronic circuits into corresponding software programs, then into formal languages, and ultimately into natural language grammars, i.e. 'syntax as machine'.
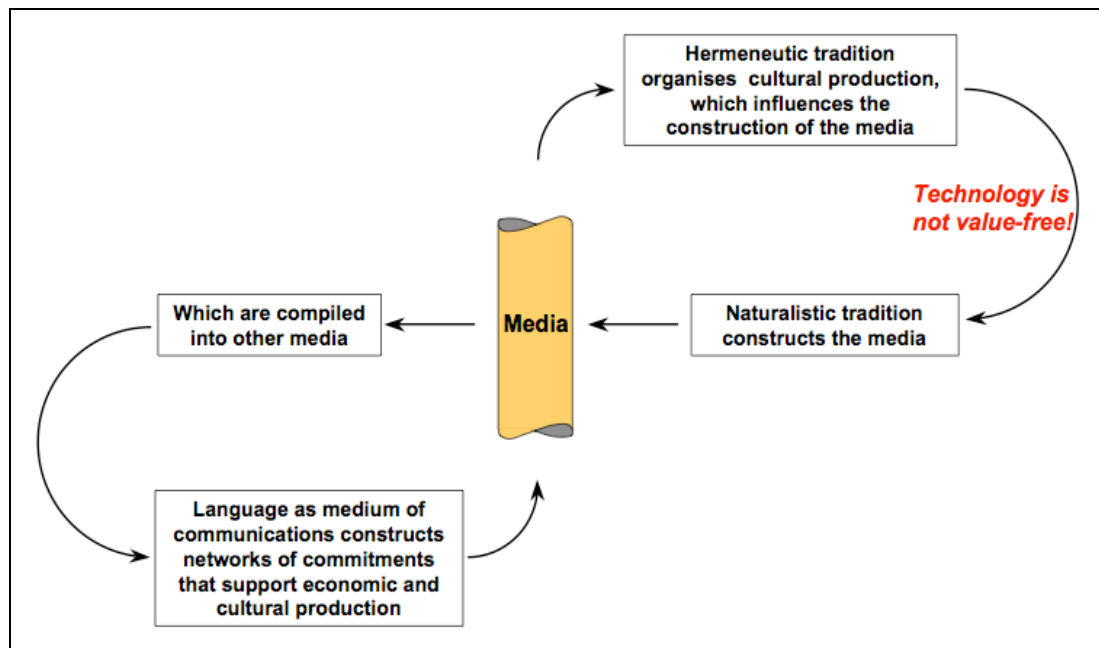

**Figure 3: Media as the nexus of different epistemological currents:
the kernel of a Foucauldian 'knowledge society apparatus'**

By progressive abstraction, we encounter the still-open debate about the signifying capacity of syntax vs. semantics. At this preliminary stage of (meta-)theory construction we gloss over the finer points of this debate, claiming that we have a 'language' – which can usefully underpin social constructivist processes involving human beings. Such processes, in turn, mediate the formation of social groups, institutions, and economic and cultural production. Such intangible artefacts of the knowledge economy are then channelled through ICTs for wider distribution and consumption. The life of a society or an economy is studied by social science. If we start from social science and humanities concerns with cultural expression and production, i.e. with the *message*, we can draw upon critical theories of technology (Feenberg 1991, 2002) which indicate that our technologies embody cultural values and, reciprocally, that our cultures influence the technologies that are produced, thereby closing the cycle. It was through interdisciplinary dialogue and exchange that this understanding of DEs as a system was achieved by the collaborating researchers from different disciplines who were engaged in the OPAALS project.

Another outcome of OPAALS's interdisciplinary collaboration and exchange was the emergence of new ways of thinking about problems usually firmly rooted in discipline-specific ways of working. As the work of the project progressed, many of the natural, physical, and computer scientists working in the project came to appreciate the concept of reflexivity and developed a greater awareness of the implications of 'paradigms' (Kuhn 1996). The task of writing a report together with social scientists and critiquing the software architecture (Moschoyiannis et al. 2008) provided computer scientists with the opportunity to discuss the aspects, from a social science perspective, of the requirement that the

architecture of a DE be fully distributed. However, the discussion did not go as far as to question the normative character of this requirement. In other words, the science and the engineering parts of the project were 'colonised' by social science perspectives and sensibilities only to an extent that was considered 'safe'.

The OPAALS project also embraced research on DEs drawing on possible interpretations and applications of social network analysis (Colugnati et al. 2008). This ranged from the concept of a scale-free network to the implementation of an agent-based simulation environment specifically designed to visualise social networks of partners, SMEs, and user communities in Brazil and India.[13] This development can be seen as a reciprocal colonisation of the social sciences by the sciences.

These developments offer lessons in the possibilities of radically interdisciplinary research that aims to include perspectives from disciplines as divergent as the natural, computer and social sciences. These possibilities are centred on the notion of collaboration between researchers and their domains of expertise that retain a strong disciplinary identity, yet are willing to stretch outside their comfort zones to engage with, and attempt to understand, alternative perspectives. These possibilities of interdisciplinary collaboration require a willingness to experiment with alternative ways of representing knowledge and ideas.

The diagrams included in this paper are illustrative of this point. They originate in the language of engineering and are appropriate for expressing systemic ideas. However, they can also be used to 'interpret' and 'fix' social sciences ideas in a way that is helpful for those with backgrounds outside the social sciences. Interdisciplinary collaboration requires 'trying out' thinking patterns that emerge from the epistemological perspectives of other disciplines: in our case this resulted in a constant oscillation between objectivity and subjectivity. This oscillation needs to start and end somewhere – more often than not the researcher's 'home' discipline – but the process itself is valuable and allows for shared, applied goals to be achieved and new insights to be developed. The perspective on interdisciplinarity that emerged from OPAALS suggests that valuable outcomes can be achieved at the applied level and valuable social or cognitive dynamics can be achieved at the theoretical level. However, a key insight pertains to the impossibility of interdisciplinarity and the search for unification (that is, merging two unrelated phenomena under the same theoretical model). The fact that OPAALS included mathematical physics, cell biology, abstract algebra, and theoretical computer science led to a common perception that the theory of DEs OPAALS was working towards would be rooted in the field of Complexity Science, that is, that we would aim for theoretical and applied unification, rather than integration, between these domains.[14]

'Complexity' is a theoretical term that has been borrowed from natural science by social science with fruitful and – perhaps predictably – *complex* results. Theories of complexity originated in the natural sciences as tools for understanding non-linear dynamics, that is 'disorder – or apparent disorder – in nature, including turbulence in fluids, the erratic flows of epidemics, the arrhythmic writhing of a heart in the moments before death' (Bryant 2007: 131). This shift from a Newtonian to a non-linear scientific paradigm has influenced social philosophy (Fuchs 2003: 387). Non-linear theories, as well aiming to explicitly recognise and map observed disorder, also aim to calculate and/or reveal the patterns and structures underlying that 'chaos' so as to better harness and predict it (Bryant 2007: 133). In the social sciences, certain elements of this tradition have been appropriated and adapted as a framework to understand the complexities of the social world. Integral to the complexity approach, arguably, are two central issues:

> First, the extent to which complexity theory's concepts can be used metaphorically and second the ability of theories of complexity to model social processes. These issues are connected with two more fundamental problems. The first one concerns the way that researchers from the two different communities communicate across disciplinary boundaries. The second one relates to the underlining commensurability of notions across the two fields and questions the suitability of complexity-related ideas to model social processes (Dini and Berdou 2004: 25).

Other scholars note that 'complexity research stands only at the threshold of acceptance in the social sciences' and that it 'does not offer a well-articulated body of theory, but rather a number of more-or-less related phenomena: dissipative structures; catastrophe; chaos; self-organized criticality; and self-organization' (Campbell-Hunt 2007: 796). We suggest that complexity science cannot offer a well-articulated body of theory precisely due to the presence of conceptual plurality and incommensurable epistemological difference in the many 'more or less related phenomena' brought under the complexity umbrella. The second key lesson drawn from the OPAALS interdisciplinary research thus relates to the impossibility of interdisciplinary unification. Instead, we argue for the possibility of integration, where this is understood as efforts to enable different theories to *coexist* with a degree of compatibility that does not need to imply that the same epistemological foundation underpins them. This approach worked well for the project.

As a final example of the importance of our perspective on interdisciplinarity, computer science DE research fell prey to a trap in European Commission-funded research that is becoming increasingly visible with each R&D Framework Programme. Most EU projects in the ICT area try to respond to two sets of expectations: on the one hand, traditions of scientific research from the physical and natural sciences motivate the Commission officials to expect innovative 'advanced research' results in the form of new architectures and algorithms; on the other hand, the results of the research and of the innovations are expected to achieve the potential for market adoption and socio-economic impact. Whereas these two sets of expectations may be reasonably aligned in disciplines such as applied physics, electronic engineering, nanotechnology, or biotechnology, in ICT-related enquiries these two sets of expectations are more difficult to align. The reason is that the greater the level of innovation the less likely it is that there will be a clear pathway to its adoption. Market adoption in the software area is strongly dependent on legacy software and prior use, existing skill-sets, standards, and languages. Thus, developing an ingenious new software artefact, architecture, implementation, interaction protocol, etc., is more likely to *impede* early market adoption than to facilitate it. The research and innovation policy research objectives fostered by the European Commission would be enhanced if they were informed by these observations about the interdisciplinary challenges involved in ICT-related research.

Theoretical interdisciplinarity and applied research, as we discovered through the process of building a DE framework that could hold a variety of often conflicting epistemological positions, arguably benefits not from unification but from difference, creatively integrated, which drives innovation, communication, and social dynamics.

CONCLUSION

This paper has discussed the process of interdisciplinary collaboration and research that defined the OPAALS research project. It has provided a description of the different, yet complementary, research agendas of each disciplinary domain of the research project and given an account of the challenging questions of epistemology that arose in developing a theoretical framework for DEs. This framework was summarised in the form of a meta-theoretical framework that was specifically developed in the project to highlight and leverage epistemological contradiction and theoretical difference.

The lessons that can be extrapolated from the theoretical and applied experience of OPAALS research can be summarised in the phrase: the (im)possibility of interdisciplinarity. The core possibility of interdisciplinary research is the fact that those adhering to radically diverse disciplines can collaborate to achieve a shared, applied goal – such as the definition of an architecture for DEs in tandem with the development of an understanding of their socio-economic potential. The impossibility of interdisciplinary research is associated with the impossibility of ultimate theoretical unification among disciplines based on contradictory epistemological foundations. It is not fruitful to attempt to make them fit within the same theory. We argue that the contradictions and complexity of various disciplinary perspectives should not be approached with the expectation that they will unite into a new paradigm that transcends or eliminates received knowledge. Rather, these perspectives should be

encouraged to flourish, providing a basis for new communication and exchanges, new syntheses, and new technical and social constructions and applications.

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NOTES

[1] It is interesting to note that this optimistic view was, and continues to be, partly a consequence of 'interdisciplinary misunderstandings' based in each case on ascribing more to the 'other' discipline than it deserves because we did not understand it well enough. Thus, 'evolutionary architecture' sounds rather impressive to anyone who has not attempted to build one, and 'sustainable socio-economic development based on democratic principles, trust, transparency, and accountability' sounds very feasible to non-social scientists, but is very difficult to achieve.

[2] As the first author is the OPAALS project coordinator, the second one of its researchers, and the third a professor who co-led the project, this paper is inescapably a somewhat subjective account of the inner workings of a research project. All three authors were involved in writing project reports aiming to develop a theoretical framework for digital ecosystems; all three consider themselves interdisciplinary researchers. Paolo Dini comes from an engineering, applied mathematics, and physics background, and works at the interface between theoretical computer science and cell biology; and, separately, on social theory in relation to new media. Mehita Iqani works at the interface of the humanities and social sciences in the field of media and communications. Robin Mansell is a social scientist with training in social psychology, politics and economics as well as in telecommunications engineering who focuses on media and communication. This paper is itself, therefore, the outcome of an interdisciplinary encounter and many challenging discussions about the very different epistemologies that underlie each disciplinary tradition.

[3] The centralisation of computer science in this diagram is partly due to the fact that Directorate General (DG) ICT, which has a strong focus on digital technologies, funded OPAALS. The DG (ICT) was also known, during different framework programmes, as DG Information Society (DG INFSO), DG Information Society Technologies (DG IST), or DG Information Society and Media.

[4] Interestingly, according to Floridi 'in the genetic code, the medium (the genes) is the message' (Floridi, 2010: 80), thereby suggesting that biology has been able to achieve an even tighter feedback loop than is shown in Figure 2.

[5] These include questions of distributed identity, accountability, and trust; the architecture of peer-to-peer (P2P) networks; the distributed coordination of transactions for complex long-running services; and distributed storage solutions.

[6] This area of research has focussed mainly on modelling a language called SBVR (Semantics of Business Vocabularies and Business Rules).

[7] For example, although concepts like phase transitions and percolation (Silverberg and Verspagen 2005) have been used to describe and even model the interactions between companies in the context of innovation economics, a fundamental ontological and epistemological incompatibility remains between the concept of socio-economic relations between firms in the latter and the concept of interaction potential between molecules in the former.

[8] For a more detailed discussion, see Chapter 3 of Dini et al. (2009).

[9] Although, as shown above and discussed by Hollis (1994), Quine (1951) usefully extends Popper's theory, we take the concept of falsifiability as the main point of reference, which Quine's ideas also support, albeit at a more abstract level.

[10] It is tempting and it would be quite interesting to paraphrase this slogan into 'Liberate European research from the demands of European Commission politics', and then to proceed with an analysis of what might motivate such a slogan. But this would take us too far from the focus of this paper which is on interdisciplinarity.

[11] We are not conflating the two concepts here, but depending on the discipline, they can have reciprocal roles. For example, within the objectivist epistemology of physics we can accommodate different disciplines such as chemistry and various branches of engineering. By contrast, within social science as a disciplinary domain we can accommodate different epistemologies (objectivism of mainstream economics, phenomenology, social constructivism, etc).

[12] The shifting nature or perception of software between 'linguistic artefact' and 'machine' is well reflected in the differences between how software as intellectual property is addressed in Europe where it is mainly protected by copyright vs. the US, where it is protected by patents.

[13] See http://evesim.org/

[14] Using the definition of these terms we have proposed, it is interesting to note that people from the sciences tend automatically to aim for unification, whereas people from the social sciences as a rule have more modest aims towards integration. We think this is a consequence of the different levels of awareness in these two disciplinary domains of questions of epistemology. In the sciences and engineering 'life is easy' since physics provides good answers for most 'fundamental' questions. In the social sciences, researchers have become used to proceeding with caution.