Replication of routine, the domestication of tacit knowledge and the economics of inscription technology: A Brave New World?

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1. Introduction

For the French anthropologist C. Levi Strauss (1967), the task of anthropology was to discover the *whole man* through human works and expressions, his distinction between cultural and social anthropology. For Levi Strauss and other social scientists, the production of *individual* works and expressions are of less professional interest than the reproduction of works and expressions that transcend and thereby often obscure their maker in becoming ubiquitous and utilitarian physical artefacts or cultural constructs. Indeed, Levi Strauss believed that the principal value of examining these works and expressions was to discover in their invariance clues about fundamental and universal features of the human mind.

Economists as well as anthropologists have an interest in reproducible human works and expressions. In this paper, we depart from the highly instrumental and overly simplified assumptions that usually characterise the economic analysis of reproducible human works and expressions. Our purpose is to develop an analysis of the processes of 'inscription,' i.e. the composition of scripts facilitating the reproduction of human works and expressions. In particular, our focus is on how humans reproduce their knowledge and understanding, their know-what and know-how, in forms outside of themselves. Stated in this way, many now familiar concepts in the economics of technological change, including the reproduction of organisational routines and the 'codification' of knowledge, may be addressed through an exploration of 'inscription technology.' In this paper, we can do no more than to identify some of the features of this analytical approach, illustrate it with examples, and consider its relation to that of Nelson and Winter (1982).

The evolution of inscription technologies, particularly those involving the use of information and communication technologies (ICTs), is altering skills and routines in codified forms of knowledge. We believe these changes have important implications for policy and practice. We recognise the claim that ICTs provide new opportunities for inscription is controversial and re-echoes many of the claims made in the latter half of the 20th century on behalf of automation, artificial intelligence, and applied system analysis. We develop our argument regarding inscription technologies in two phases. The first involves an examination of specific technologies and their relation to individual human skills and organisational routines. Inscription technologies influence the capacities for achieving organisational co-ordination as they provide a major method for ‘registering’ (creating a cognitive framework for expected action and response) and, thus, enabling an individual to take account of others’ actions. The second phase takes up the question of how the representation of knowledge influences the potentials for inscription, in which we find the anthropological literature on the distinctions between aural and literate cultures both evocative and suggestive. We begin with two simple observations about inscription processes that further define our intentions and help to locate our investigation within the existing literature regarding evolutionary economics.

The metaphor of evolution as applied to economic thought, as evoked by Veblen (1898/1961) and as implemented as contemporary economic discourse by Nelson and Winter (1982), is particularly useful in highlighting the roles of variety generation and the nature of the selection environment. The evolutionary economics metaphor has, however, been less successful in identifying the processes by which inheritance is transmitted. In short, it is a quasi-biological theory with birth and death, in which there is no clear analogy to reproductive behaviour and consequence. Our intention in this paper is not to solve the mysteries of sex and ‘organisational genetics’ in evolutionary economics but instead, to localise reproductive behaviour in the processes of inscription. This aim is quite similar to that originally pursued by Nelson and Winter (1982) in examining the interaction between individual skills and organisational capabilities as the basis of organisational routines, which they proposed as the genetic material shaping organisational behaviour. We take issue and depart with their conclusions in only one respect. Nelson and Winter (1982: 1356) contend that the ‘great challenge of the subject of “organisational genetics” [is] to understand how the continuity of routinised behaviour operates to channel organisational change.’ We contend that the most fertile source of organisational change is the disruption or dislocation of routinised behaviour, specifically the introduction of new methods of inscription for expanding the repertoire of individual skills and the new methods of co-ordination for assembling these skills into routines.

Our second observation is that the processes of inscription like those of reproduction often occur behind doors closed to the behavioural scientist. To understand the variety of these processes, we must engage in reflection and introspection. This process is, however, unlikely to yield an understanding of the prevalence of any particular behaviour. Myths about inscription processes are as prevalent as myths about reproductive processes. Thus, our primary concern is with elucidating some of the fundamental features of inscription behaviours, rather than assessing their prevalence or effectiveness. For some, our unwillingness to engage in an evaluative ordering of inscription behaviours will prove frustrating. In particular, we maintain an agnostic position regarding tacit knowledge, which we regard as no more fundamental or essential to the reproduction of human expression or works than other mechanisms for reproductive activity. We share Nelson and Winter's (1982) deep scepticism about the neoclassical assumptions that knowledge is universally available and that firms are therefore indistinguishably 'representative.' We demur about the predominance they assign to tacit knowledge as the mechanism for individuation of individual skills and organisational routines. Even before considering the arguments of sociologists and historians regarding the situated nature of knowledge and understanding, we recognise that making knowledge explicit and reproducible is an inherently difficult problem. As academics, it would be difficult for this conclusion to escape our attention. We believe, however, that the tendencies to view tacit knowledge as irreducible within Nelson and Winter (1982) is a case of revolutionary excess that has had the unfortunate effect of mystifying processes of inscription, learning, and co-ordination as they actually occur in modern firms. In this matter, however, Nelson and Winter (1982) left a large and open door by declaring that the subject of organisational genetics has barely been defined and the real work remains to be done. Despite related efforts such as as Andersen (1994), Dosi (1997), Loasby (1983), Metcalfe (1993, 1998), Marengo (1992), Silverberg *et al.* (1988, 1994), and Witt (1985, 1992), this door remains open and much work remains to be done.

The essence of our argument is that new opportunities are emerging for reconfiguring the reproduction of human expression and works, with the potential for transforming the rate and direction of both variety production and selection. The influence that these new opportunities has depends, in part, upon whether policies and practices supporting their development can be constructed and, in part, upon their inherent capabilities for development and articulation. The inherent capabilities of these new techniques may serve to produce new expressions that differ as significantly from our current (modestly) literate culture as our own culture differs from the aural cultures of pre-literate societies.

2. Replication of Routine: The Role of Inscription

Nelson and Winter (1992) offer a rich and suggestive account of the role of organisational routines as embodying what is known by the firm.[1] Nelson and Winter base their understanding of routines upon three components: 1) the repertoire of organisational members' capabilities, 2) the exercise of these capability repertoires through a process of 'remembering by doing,' and 3) the co-ordination of these repertoires within the larger system of the firm through the transmission of messages. The abstraction from purposive activity employed in defining the third component is particularly important for creating an evolutionary theory of organisational behaviour. The message senders may have a 'plan' as to the expected response to their messages. As Nelson and Winter (1982: 107-12) make clear, however, in their discussion of the routine as a 'truce,' this plan is less important than the combined effects rule-motivation for individual behaviour accompanied by enforcement and a shared acquiescence to organisationally appropriate behaviours. Organisational coherence, therefore, is an 'emergent' property of the incentive and social system.

Our contention is that each of these components is undergoing important transformations resulting from the changing characteristics of economic output in advanced economies and the ever more wide spread of information and communication technologies.

With respect to the first two components of routines, while Nelson and Winter utilise the assembly line to exemplify the idea of capability repertoires, we emphasise the growing dominance of organisational entities such as the project-based and knowledge-based service industries in industrialised economies. In these entities, the opportunities for 'remembering by doing' are constrained by the limited recurrence of particular activities. In the industries that these entities populate, problems of extending and reconfiguring the repertoire of capabilities dominate repetition, defeating the effectiveness of remembering by doing. This situation arises from the combined effects of internationalisation of many conventional manufacturing activities and the attainment of very high levels in continuous processes used in some types of manufacturing (e.g. chemicals, paper, and containerised shipping). In the latter activities, many of the repetitive activities have become embedded in automation so that those workers that remain are engaged in a diverse collection of one-off or infrequently recurring problem-solving activities to keep the entire system 'up and running.'[2]

With respect to the third component of routines, co-ordination, we observe that information and communication technologies provide ever-increasing capabilities for monitoring individual performance as well as augmenting the extent to which individuals may be required to take account of each other's performances. In the sort of 'panoptic systems' invoked by Zuboff (1988), messages need not enter into the complex mediation process that Nelson and Winter characterise in terms of an emergent 'truce' among organisational members although the system as a whole may provoke resistance.[3]

Our contention that modern organisations are less likely to have the opportunity to 'remember by doing' is our departure point for re-examining the role of script construction (inscription), that serves to reproduce and extend the repertoire of individual capabilities. In particular, we ask whether the processes of inscription are likely to involve an increasing use of codified knowledge and, if so, how we may understand the character of this knowledge in relation to another of the major themes developed by Nelson and Winter, the role of 'tacit knowledge.'

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[1] This account is a particularly effective in explaining why, in the real world, processes of technological transfer do not operate according to the arithmetic of neo-classical economic analysis wherein duplicating inputs, capital, and entrepreneurs serve to duplicate output.

[2] It is important to note that even compared to twenty years ago, there has been a marked reduction in repetitive activities involved in factory equipment maintenance as methods for preventative maintenance have become systemised and instrumented. Failures that occur are likely to be unanticipated and, therefore, to involve one-off problem solving activities.

[3] A normative analysis of these developments lies outside of our discussion in this paper, although it should be of growing concern to social scientists. Technological systems that utilise human beings as functional nodes in complex networks with increasingly tight specifications may or may not observe the truce that prevailed

The process of inscription is complex. It involves transforming knowledge into a form that enables effective performance of complex tasks by individuals who may or may not have a clear understanding of the underlying principles of design or operation of the component of the system that they are called upon to operate or maintain. We wish to emphasise that the devising of an effective script for problem-solving activity is rather different from that of creating the sort of blueprint or instruction manual described by Nelson and Winter as instances of explicit information. Instead, as Nelson and Winter observe, scripts are an alternative word for skills. The problem is that the word ‘skills’ in English is ambiguous. Scripts may incorporate heuristics, experimental investigations, analogies, metaphors or other figurative expressions that employ the natural language abilities of the intended recipient. In this sense, devising an appropriate script involves the design of behaviour rather than understanding. Correspondingly, many of the concerns raised by Nelson and Winter about the difficulties of articulating, including time-rate difficulties in utilising explicit information or the difficulties of parsimonious description, are dubious. They are more successful in reminding readers that scripts, regardless of how they are acquired, are ‘internalised’ in much the same way as an actor may mediate between the memorisation of a text and the actual performance of the part.

The principal questions to ask about the effectiveness of scripts is whether the person employing it will: 1) be able to master the outlines of the script in sufficient detail to execute it, 2) will engage in the appropriate set of behaviours suggested by it, and 3) successfully ‘follow’ it (i.e. continue to use it as a guide) despite inevitable departures and improvisations. It is certainly possible to devise ‘bad scripts’ that are too detailed to be effectively executed, that provide little guidance as to appropriate behaviour, or that fail to be robust against improvisation or other departures occurring during their execution. These possibilities should not be taken as demonstration of the inability to articulate knowledge in explicit or codified forms through the use of appropriate scripts. Nor should the variability with which individuals are able to internalise and execute scripts, the observed differences in ‘talents,’ be taken as evidence of a fundamental inability to articulate knowledge. Like Nelson and Winter (1982), we have no problem with the

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in the organisations contemplated by Nelson and Winter with the consequences that they identify for strife and confusion.

recognition that substantial variation exists in human talent and that these variations create heterogeneity that remains largely unrecognised in conventional economic theory.

We now turn to an explicit examination of knowledge explicitly articulated or codified as scripts with a view to examining what has remained constant and what has changed in the technological opportunity for inscription in the two decades since Nelson and Winter examined the issues of skill acquisition.

One starting point is to examine the meaning of 'blueprint,' previously a method of codifying knowledge about the dimensions and relationships among the components of an artefact. Blueprints involve graphical expression and a limited extent of writing. Most of the blueprints created in 1982 involved the skills of a 'draughtsperson,' capable of rendering design ideas or extant objects through the use of 'multiview orthographic projection' (standardised renderings of the object from orthogonal lines of sight using fixed rules of perspective).[4] The blueprint of 1982 was simply a visual representation of a real or planned artefact. The 'language' of 'multiview orthographic projection', in general, provided a barely adequate basis for the reproduction of the object in question (Belofsky, 1991). The scripts required to transform blueprints into artefacts or artefacts into blueprints involved a considerable repertoire of skills.

Since 1982, substantial advance has occurred in the meaning of the term 'blueprint.' Contemporary engineering diagrams are capable of incorporating precise information about curvature, sufficient data to allow the visual representation of the artefact from any viewing angle, and the possibility of additional information allowing virtual simulation of the artefact's performance under various environmental conditions. Further, it is possible to link 'blueprint' data for some artefacts to fabrication equipment able to create the artefact from the blueprint and to digitise the surfaces and dimensions of artefacts to create a blueprint. The most advanced example of this capability is the design software for integrated circuit devices that allows the

[4] Early versions of computer aided design existed in 1982 but their use was relatively limited. At the time that Nelson and Winter were constructing their book, John Walker and his colleagues at AutoDesk were developing the first personal computer-based computer aided design software, AutoCad, which has since become the dominant software application in this field, see Walker (1994).

fabrication of the most complex artefacts yet known to human beings to proceed entirely automatically from computer-aided design ‘blueprints.’[5]

The illustration of the evolution of blueprints highlights several points that have recently been made in the economic literature on knowledge codification (Cowan and Foray, 1997). Codification of the sort of knowledge represented by ‘blueprints’ requires an explicit physical model of the artefact which may be embedded with varying degrees of precision in the ‘blueprint.’ For example, the codified knowledge may or may not record the detail that spanning beams deform as the result of the load (including their own weight) that they bear. Such ‘blueprints’ also involve the development of appropriate languages and their use involves the development of further technologies (e.g. the replacement of the manual copyist by electronic printers). It is not obvious whether there is a higher or lower level of ‘tacitness’ in the skills of the individual employing these new technologies.

One of the reasons that it is difficult to evaluate the change in drafting skills is that they are situated in relation to particular classes of artefacts, architectural drafting does not involve the same types of knowledge as drafting for electronic artefacts. In each case, the skill of the draughtsperson arises from the interaction between the practices of representation and of fabrication. For the visual language to provide a useful guide to the fabricator, the draughtsperson must become aware of the particularities involved in fabrication that create ambiguity in the visual representation of the artefact. In cases where the linkage between draughtsperson and fabricator is direct and local, languages and conventions of practice emerge that are situated and not standard.

As more individuals from different organisations and backgrounds become involved in the use of blueprints, the particularities of the blueprint producer-user relationship evolve towards standardised expressions. This is essentially the same process as occurs in the internationalisation of languages. Unlike language, however, the terminus of the process of blueprint evolution is the

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5 The claim that integrated circuits are the most complex artefacts is based upon the number of their discrete components and the exclusion of biological systems from the definition of artefacts. Dolly, the cloned sheep, is a more complex artefact than the most advanced integrated circuit if you wish to label her as an artefact.

automation of fabrication, the blueprint becomes the fabrication script, as in the case of IC fabrication. While tacit knowledge may still be involved in creating blueprints that may be reliably fabricated by automated methods, the tacit component in the translation of the blueprints into fabricated artefacts has disappeared.

The economic consequences of the replacement of the draughtsperson as the interface between designer and fabricator are, of course, economically significant for the draughtsperson. Are these consequences economically significant for society more generally? In the case of integrated circuit design, the capability to create standardised modules for the implementation of electronic system designs has supported the emergence of 'fabless' integrated circuit companies. Although the economic viability of these companies was initially disparaged by established producers familiar with the problems of integrating design and fabrication, companies offering silicon 'foundry' operations (the fabrication task) for fabless integrated circuit designers have emerged as a stable feature of the integrated circuit industry.

In this case, then, the economic significance of achieving more explicitly codified knowledge is a transformation of industrial structure. The production of customised integrated circuit designs is a significant bottleneck in the development of a vast collection of producer equipment and consumer durables with 'embedded intelligence.' The ability for new entrants (both fabless integrated circuit firms or, if sufficiently large, equipment producers) to employ designers specialising in system development offers significant new opportunities for variety creation and the accumulation of the user-specific knowledge sustaining organisational diversity. These implications are significant for regional competition, for employment in the electronics industry, and for the further development of integrated circuit fabrication technology.

3. Inscription and The Domestication of Tacit Knowledge

The processes of inscription are not confined to the purpose of reducing the design-fabrication link to a deterministic process. Modern technologies provide ways to 'inscribe knowledge' that can have a major influence on the acquisition and exercise of skills that are not or cannot be completely specified. Audio-visual recording allows people to generate 'facsimile' records of aural and visual images. The exercise of skills that involve physical actions can be recorded. ICT-based capabilities (sensor instrumentation, automatic hidden surface graphic generation, etc.) can further augment the recording process. The resulting facsimile recording has the information economic features of codified knowledge, its transmission and reproduction can be accomplished inexpensively. In this respect, facsimile reproduction provides a means of capturing some of the features of tacit knowledge, or what Cowan, David and Foray (2000) label 'unarticulated knowledge.'[6] In other words, new technologies produce a sort of convergence between codified and tacit knowledge in terms of their "technical reproducibility" (to adopt the famous expression of Walter Benjamin, 1939/2000).

While for a long period it was easier and less costly to technically reproduce codified and written expressions – and this was considered as a unique attribute of codified knowledge – we are entering the era of low cost reproduction of facsimile representations of tacit knowledge. Hence, low marginal costs for reproduction and transmission are no longer the privilege of codified knowledge. Is codified knowledge losing its singularity? Does this evolution provide a rationale for lowering investments in codification capabilities and re-directing ICT architecture and application towards creating infrastructure for inscribing and circulating tacit knowledge as facsimile representations?

To more precisely answer these questions requires an explicit and empirical understanding of learning. Historical experience does not necessarily provide an accurate guide. For example,

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6 This usage concurs with Nelson and Winter (1982) who state 'whether a particular bit of knowledge is *in principle* articulable or necessarily tacit is not the relevant question in most behavioural situations. Rather, the question is whether the costs associated with the obstacles to articulation are sufficiently high so that the knowledge *in fact* remains tacit', p. 82.

quite impressive facsimile reproductions of piano performances can be created using ‘piano rolls’ (an adaptation of the programming technique first employed in the Jacquard loom) and their modern equivalent. It is, however, futile to attempt to learn to play ragtime by following the script of a piano role inscribed by a Scott Joplin performance. This, however, is not the end of the story. A vast number of commercially successful systems have been devised to teach people to play the piano by connecting a keyboard to some type of microcomputer system. The fact that no world-class performer has yet emerged whose training was based upon following automated teaching programs may be a testament to an irreducible tacit component in teaching piano. Alternatively, however, it may reflect the fact that sufficient investment in the cumulative improvements of such teaching machines has not yet been made. In part this may also be the consequence of the rather large supply of piano teachers with excellent training and skills.[7] In this sense, the contribution of facsimile recording as a means for skill acquisition have only begun to be explored.

We believe that it is possible to go further, however, than saying ‘it depends’ with respect to this competition between facsimile recording and codification. To do so, we draw upon the work of anthropologist J. Goody on the role of writing in the production and accumulation of knowledge (see Goody, 1977, 1986, 1987, 1996). This work introduces a fundamental distinction between a “first-degree of codification”, involving the facsimile reproduction of aural and visual images requiring no *a priori* development of a particular knowledge representation, and a “second-degree of codification that requires *a priori* modelling to express knowledge in a system of “graphemes”. Goody provides a rich and well-illustrated framework for reconsidering the role of second-degree codification: why it is important; what functions can be carried out only by it and how the impact of knowledge codification on the marginal costs of storage and transmission can obscure a larger function of codification - the support it provides for the creation of new cognitive structures.

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7 We cannot help observing that this supply is substantially augmented by the mass production and distribution of piano playing scripts called sheet music and the availability of recorded music allowing one to hear what a world class performances should sound like.

3.1 The ‘visible’ function of codification: on storage and transfer

Basically, knowledge codification has two functions. The first is the function of storage and ‘transfer’ that permits signalling over time and space and provides humans with marking, mnemonic and recording capabilities. The French anthropologist A. Leroi-Gourhan (1965) claimed the “unique quality of man of being able to put his memory outside himself”. When codifying became common, as Goody writes (1977, p.37), “no longer did the problem of memory storage dominate man’s intellectual life”. This function is examined in this section. It provides a basis for examining the first order gains in the transition between pre-literate and literate society. We contend that this transition is analogous to that between unarticulated tacit and codified knowledge. When knowledge is tacit, its reproduction must occur through an inscription process involving inter-personal interaction, the master guiding the apprentice. Literacy and similar skills involved in the codification and de-codification of knowledge alter the roles of the master and the apprentice, augmenting both of their capabilities. Again, this is not the end of the story, however.

Codified knowledge itself has unique properties arising from the use of symbolic representation. The ability to manipulate symbolic representations to reorder, juxtapose, visualise, and manipulate provides a basis for transforming the knowledge that it represents. This is the second function of literacy and knowledge codification, which we discuss in the following section. It is the basis for the second order effects of literacy and knowledge codification. As we will see, the second order effects may dominate the first order effects.

3.1.1 Re-enforcing memory and providing learning programmes

The codification of a certain kind of knowledge (know how) generates new opportunities for knowledge reproduction. For example, a written recipe is a ‘learning programme’ enabling people, who are not in a direct relation with who is possessing the knowledge, to reproduce it at a ‘lower’ cost. Goody writes (1977, p.143) : “The written recipe serves in part to fill the gap created by the absence of Granny, Nanna or Mémé (who has been left behind in the village, or in the town before last)”.

"In part" is the important phrase here. Naturally, codification mutilates knowledge. Getting the written recipe does not totally suppress the learning costs. But these costs are lower when there is a written recipe. In this sense codified knowledge can be considered as a partial substitution for the traditional way to transfer knowledge; a solution to the failures of systems of transmission based on face-to-face interactions.

The solution that predominated for a long time was that of a sufficiently large and stable population of people who retained, and in many cases captured, the tacit knowledge. In large companies and in industrial clusters, it was the internal labour market, which for a long time had had the function of memorising, transferring and accumulating knowledge (Lam, 1999). The stability of employees and their mobility in a clearly delimited area are essential elements in such a system of memorisation, accumulation and transfer of knowledge. Some centuries before, the craft guild played the same role (Epstein, 1998).

In this sense, codification should not be analysed as a substitute for tacit knowledge but rather as an alternative and complementary means of accomplishing functions traditionally fulfilled by the internal labour market and other professional networks in the field of 'knowledge management.' Internal labour markets, however, are approaching a state of crisis, in which increasing externalisation, turnover and mobility are making the traditional methods of knowledge management, based upon localisation of tacit skill transfer, ever more uncertain. For example, large companies used to bring in a replacement two years before an engineer was due to retire, so that the transmission of expertise took place smoothly between teacher and learner. In such cases, the conditions were propitious for ensuring that the professional community itself ensured the memorisation and transmission of knowledge from one generation to the next.

Today young engineers arrive just a week before their predecessors leave. As a result, other ways of transmitting expertise have to be found, as those based on the teacher-learner relationship no longer function. Furthermore, the evolution of these labour markets, from broadly defined jobs and continuous careers towards narrowly-defined jobs and stratified careers, is making the accomplishment of knowledge management functions by these markets more difficult (Lam, 1999). Codification seems, finally, to be the solution to shortcomings in the traditional ways to transmit and memorise knowledge, supported by professional communities.

3.1.2 Delivering the apprentice from a subordination relation

The other side of the first function of codification deals with the locus of power in social institutions. Goody (1977), again, offers acute observations. Codification depersonalises knowledge. The written recipe is acquiring independence from those who are teaching it. It becomes more general and more universal. It reduces the subordination relation between the master and the apprentice and this 'liberation' has at least two meanings: from a social point of view, the apprentice can learn when he has decided to do so and does not need to wait until the master is willing to teach. From a cognitive point of view, 'the human mind was freed to sudy static text (rather than be limited by participation in the dynamic "utterance'") (ibid., p.37).

The other side of this evolution is, however, the weakening of sub-cultures and local practices, since, as Goody wrote, 'the "secrets" of one group were being made public to all others' (Goody, 1977, p.142). A remarkable feature of some of recent treatises on knowledge management is their lack of consideration for issues of incentives or resistance to making an individual's knowledge more explicit. The ability to retain their employment and command the wage they receive very often depends upon the difficulty of reproducing the skills or situated knowledge of individuals. Making their knowledge more explicit and available to others may have many consequences, few of which are likely to be directly beneficial to the individual originally retaining the knowledge.

A fundamental trade-off therefore exists between tacit and explicit or codified knowledge. Whatever fundamental problems or costs there may be attached to making knowledge more explicit, these are likely to be higher because of the incentive problems. If routines and the jobs performing them were stable, the underlying sources of difficulty in making knowledge sufficiently explicit to improve the technologies of inscription would only be a matter of scholastic debate. The scale and pace of disruption, arising from technological change, organisational transformation, and a changing international division of labour widens the significance of and the audience for this debate as well as the consequences of its resolution.

For example, one of the features of the European labour market that is often criticised by market liberals is the regulation of job tenure, often seen as a major source of ‘inflexibility.’ This same inflexibility, however, offers a greater degree of incentive compatibility for some workers to co-operate in making their knowledge explicit. Rather than hoarding a stock of knowledge as a means for maintaining stable employment or frequently changing employment in search of higher returns to accumulated expertise, job tenure offers the possibility of transferring knowledge and skills in a more orderly fashion. Of course, the value of transfer may diminish in areas where technological change is particularly rapid or disruptive. It also assumes that individuals crave new challenges and problems, which cannot be claimed to be a universal human characteristic. A growing body of the industry studies literature calls attention to significant improvements that are being made in productivity and innovation in ‘low technology’ industries. It is possible that there has been an excessive focus on the contributions that ‘high technology’ industries, with their very high disruption of existing knowledge bases, can make to Europe given the social chapter provisions on job tenure. Policies that may be derived from this type of argument include supporting the conditions for growth of industries with more stable or incremental technological improvement and devising new forms of social insurance that allow employers in high technology industries greater flexibility in re-combining labour.

The point of this example is not to reach a definitive policy conclusion, but to indicate the ‘stakes’ involved in a deeper understanding of the role of inscription technologies for industrial and technology policy. Shortcomings in our understanding of the variety and use of inscription technologies hinders the formation of rational or evidence-based policy, substituting ‘shots in the dark’ reasoning such as the promotion of variety suggested by evolutionary theory or the emphasis on selection processes suggested by market liberalism. Neither policy may be appropriate for all times and places.

3.2 Shifting knowledge expression to graphical representation

As noted earlier it is possible to obscure the full value of explicit means of knowledge representation by exclusively focussing on the immediate gains, or even the incentive problems raised in the preceding section, from making knowledge more explicit.

Aural societies have alternative technologies of inscription that support memory, communication and learning. In particular, they develop powerful cognitive mechanisms to create and support individual and collective memory. This is what Dagognet and other anthropologists show in describing the rituals and customs that aural societies apply to retain memories (see Dagognet, 1995, Severi, 1994). Creating a repertoire of 'mnemotechnics,' these societies generate cognitive tools for enabling individuals to use effective ways to memorise knowledge and information as well as for giving the society as a whole the means to maintain a solid and robust inter-generational collective memory. For example, the development of clan systems with all of their associated ritual of membership provides an inter-generational capacity to assure genetic variety, engineer the division of labour, and stabilise the striving for dominance among human populations. Mnemotechnics may also be employed for very specific technologies such as the removal of tannic acid from oak acorns, providing a means to transfer this technology between generations, and more importantly, increasing the difficulty for any particular group to monopolise the essential knowledge for collective survival.

In our contemporary context, new ICTs that enable the recording of voices and images, provide a means of 'facsimile' reproduction. This means of codification involves a very low level of translation between bits and tones or pixels and little or no 'higher level' codification of the structure or meaning of the recording. This important new feature of the knowledge-based activities enabled by the new generation of ICTs allows the transmission of and long-distance access to all kinds of knowledge, far beyond the category only of codified knowledge and written instructions. According to the French cognitive scientist Pierre Levy, "new ICTs are closing the brackets of centuries of knowledge transmission through writings."

There is, thus, a sort of convergence (of course, largely ahead of us) between various kinds of knowledge in terms of marginal cost of storage and transfer. In this sense, codified knowledge is losing its singularity as a category of knowledge that is more appropriate than other categories for achieving the operations of storage and transfer at low marginal costs.

This is the reason why it is important to consider a second function giving to codification a unique character. This second function is the translation of holistic aural or pictorial expressions into symbolic content, stripping away their individually expressive character that imbues codification with a unique role in the knowledge economy.

In particular, the second type of codification shifts language from the aural to the visual domain, making it possible to arrange and examine knowledge in different ways. A vast array of symbolic representations is encompassed by this second function of codification. The creation of lists, tables, formulae, blueprints, and virtual models is an instance of progressively more complex symbolic codification. Even a 'simple' list could not be created without some kind of codification. In the same vein, tables open the path towards taxonomic and hierarchical structures (Slaughter, 1985). While such structures can be created by aural inscription technologies, they are encysted and static stores of information rather than tools for the extension and re-ordering of knowledge. Tables and formulae, which are the basis for mathematical constructions, become meaningful when they may be visualised and manipulated in a space; all actions that codification makes possible.

Codification provides a spatial device to screen and classify information, opening new opportunities for the modelling or representation of knowledge, a condition for rapid knowledge production and accumulation. Knowledge representations are made as a prelude to the act of inscription, the acts of inscription shape the nature and appropriateness of knowledge representations. One may therefore learn more about the processes of inscription by examining the variety and evolution of knowledge representations.

In particular, the type of code has cognitive implications. Several different types of knowledge representations and their associated codes may be identified for purposes of illustration:

Natural languages based on the alphabetic system as well as written ideographic symbols can support knowledge accumulation. Natural languages are particularly demanding for the 'absorptive' capacities of the receiver because of the extremely complex network of cognitive associations that are evoked by the idea of the 'native speaker' and, still further, the 'educated native speaker.' In practice, the codification of knowledge using natural language often involves the creation of written discourse in which interpretation and comparison provide the cognitive clues for reconstructing knowledge. Even the most straightforward and 'instrumental' usage of natural language is likely to generate a discourse. For example, as Goody (p. 136-37) indicates with respect to the 'recipe,' natural language encoding is often supplemented by comment and addition. Secondly, discourse occurs through individual experiment, assessment, and the isolation of common elements. These portions of the discourse are 'latent' in the technology of inscription referred to as 'learning to follow a recipe,' and thereby extend beyond the written content of the recipe.

Formal logical structures such as software languages dramatically reduce the complexity of associations inherent in natural language with the aim of eliminating ambiguity in expression. As all those who have produced software have learned, the absence of ambiguity makes knowledge representation a tedious process. The first four generations of programming languages[8] have aided the division of labour in software production without advancing the process of knowledge representation very much. Arguably, Bricklin's invention of the spreadsheet (a tabular knowledge representation) has made greater contributions to the use of ICTs for knowledge representation than any of the formal programming languages.

The development of specialised software for representing knowledge structures has been heralded as a means to fill the gap between natural language and formal logical structures. Most commonly called 'expert systems,' these systems create rule-based inference systems that can incorporate a degree of formalised ambiguity. They have proven of some value in highly situated contexts, such as the reproduction of experience in chemotherapy for cancer. The shortcomings of these systems lie in their cognitive structure. Since the system is not able to recognise 'relatedness' except through enumeration, the resulting knowledge representation is exceedingly complex and discards most of the advantages of other simpler forms of codification which are far more flexible to modification in both content and structure.

The development of simulation technologies for virtual representations of real world structures constitutes an alternative and complementary path for knowledge representation. A good simulation model for a system or artefact makes it is possible to manipulate elements to examine the interactions. Current techniques in simulation modelling make it possible to create new knowledge, i.e. knowledge that was not explicitly codified in the design of the simulation, through the use of simulation models. Although simulation models are still relatively expensive to create, they are becoming an essential tool for the design and study of a vast array of systems. In many cases, effective knowledge acquisition can be accomplished through experience in the use of simulation models. The training of commercial pilots to fly new types of jet aircraft involves a predominance of simulator over 'real world' experience.[9]

During the last few years, a much more promising structure for knowledge representation, the World Wide Web, has begun to emerge. The virtue of this representation technology is that it simultaneously provides a means for expressing information as 'quanta' and establishing inter-relations between this information. This feature, first referred to as 'hypertext' but now better labelled 'hypermedia' in the light of the possibilities to incorporate audio-visual representations as information quanta and 'maps' of the inter-

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8 These generations were 1) Assembly language , 2) 'unstructured higher level' languages such as Fortran, Cobol, and LISP, 3) structured higher level languages such as Algol, C, and 4) object oriented and 'inheritance' languages including Java, Small Talk and Eiffel.

9 The principal reasons that the total hours of 'real world' flying are often higher are a) it is cheaper to gain initial experience in light aircraft, b) military training de-emphasises simulator training, and c) many pilots enjoy flying in the real world. Arguably, none of these have much to do with the tacit nature of the skills needed to fly aeroplanes that cannot be effectively simulated.

relationships, offers an extremely flexible system for knowledge representation. It incorporates all known forms of graphical information representation. The principal problems of the World Wide Web as a system of knowledge representation are:

a) there is currently no means for 'validating' information with regard to any standard of authority; e.g. the instrumental agency of UFOs in determining crop forecasts has the same standing as weather forecasts;

b) the architectural complexity of inter-relationships among information is capable of indefinite and arbitrary expansion so that it is very difficult to derive deeper structures of hierarchy; e.g. the difficulty of constructing search engines that do more than identify information quanta;

c) the proliferation of standards of information representation which raises the costs of accumulating skills in synthetic information assembly tasks, a necessary part of inscription.

None of these problems is inherent to the basic structure of the World Wide Web but, instead reflect the dominance of variety generation over selection processes operating in the first decade of the system's operation.

One may think of these examples of knowledge representation as successive attempts to address specific problems in knowledge representation with the aim of improving the methods for inscribing knowledge. In each case, the technology of codification is related to a specific means of inscription, e.g. reading a text, executing a programme, operating an expert system, or utilising the World Wide Web. In each case, the person interacting with the information resource is engaged in a process of learning. The people who are designing these information resources have an ever greater variety of tools available for representing knowledge including a growing capacity to 'link up' with the efforts of others.

The current stage of development can best be characterised as 'early days.' The speed and coherence of advance depend a great deal upon both social and conceptual innovation that can mobilise these tools to extend the advantages of knowledge representation. Even if technological progress were to stop today, the evolution of knowledge representation using this collection of tools would continue for many decades.

4. Further Implications

The arguments outlined in this paper are important for both research and policy. We offer a few observations of these implications in this section.

4.1 Research Implications: Examining Knowledge Representation and the New Literacy

This paper has emphasised that the value of knowledge representation depends upon on the extent to which it can be successfully employed in inscription processes, learning activities involving the execution of scripts. We believe that a growing sophistication in the construction of scripts needs to accompany the growing technological capacities for representing knowledge as information. For example, while an instructional movie is obviously a type of information, it need not be an effective means of 'inscription' any more than a quantum physics textbook can provide the novice physics student with understanding. According to our argument, the problems of inscription do not arise primarily from the tacitness of knowledge, but from a combination of the incentive structures for capturing knowledge in tacit forms and a limitation in our imaginations on improving the means of inscription.

Our aim in elaborating at some length the parallels between the transition between the aural and written culture and the creation of new means of knowledge representation is to highlight the significance and inter-action between knowledge representation and inscription processes. The potentials and limitations of knowledge codification rely in a fundamental way upon our capacities for developing effective scripts. Making a film on a traditional craft technique allows people to store and have access to interesting knowledge. The creation of this information is subject to increasing returns in the sense that there are high fixed costs to produce the first copy and very low marginal costs to produce and diffuse additional copies. But this is a first degree of codification that does not involve any generation of new knowledge structures and representations. In particular, it is not possible to query the facsimile reproduction for the effects of interactions that are not depicted, as it would be to query a simulation model. Nor is it possible to provide an interactive link to knowledge about particular components of the process, allowing the viewer to explore them in the order and at the level of depth. This form of knowledge representation has shortcomings even with regard to the more primitive instruction manual. Although the user may be able to more rapidly memorise components of the process by viewing visual representations, a simple visual representation will provide little or no cognitive structure for understanding the information, clues that all but the very worst instruction manuals are capable of delivering.

In short, ‘first degree’ codification involves the ‘facsimile’ reproduction of aural and visual images. A ‘second degree’ codification harnesses the power of the symbolic representation of languages including mathematical modelling to provide interactive and generative potentialities. These distinctions are an important foundation for inter-disciplinary investigations into the nature of learning using encoded information and various types of scripts.

4.2 Policy implications on education, training and the economics of new ICTs

Secondly, there is a growing debate on the relationships between codified knowledge and tacit knowledge and on the role of codification in the dynamic of knowledge reproduction or exchange. In this context, it would be a mistake to emphasise too much the ‘storage and transfer aspect’ as the main ‘competitive advantage’ of codified knowledge over the maintenance of knowledge in tacit forms such as organisational routines. The next generation of ICTs will enable efficient storage and long-distance transfer of a greater variety of knowledge (including knowledge that has previously been regarded as ‘inherently’ tacit). This will serve to reduce the differences between marginal costs of storing/transferring codified and tacit knowledge respectively. But the main reason why it is a mistake to over-emphasise the use of codification as a storage and transfer device is that such an argument does not do justice to the central role of knowledge codification. This role is the creation of new cognitive devices to produce knowledge; what we characterise as the knowledge ‘representation’ problem. Thus, claiming that “the intelligent use of ICTs is as an infrastructure supporting the formation and use of tacit knowledge” (Lundvall, 1999) is only part of the story. The symmetric claim is that methods of solving knowledge representation problems may dramatically reduce or eliminate the economic resources needed for the accumulation of tacit knowledge.

The contest between these two structures of applying the technological capabilities of ICTs is reflected in some education and training debates. The overuse of images and aural instructions that can be stored and communicated at very low marginal cost can have some perverse effects. While such practices effectively provide very user-friendly environments for learning, they save the detour through some kind of modelling and graphical development, which is a key method for developing new cognitive opportunities. Such a context has profound implications for the evolution of organisational memory, routines and structure.

<u>Postscript</u>:

> The anthropologist is above all interested in unwritten data, not so much because the peoples he studies are incapable of writing, but because that with which he is principally concerned differs from everything men ordinarily think of recording on stone or on paper.
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> *C. Levi-Strauss (1967), pp. 25-6*

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