Organisation, Information and Computation

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Introduction

Organisation Studies and Computing Science are heterogeneous fields of theory and practice with long-standing interconnections, significant mutualities and important differences. This paper addresses their mutual concerns of organisation, information and computation by exploring common but problematic interests in the formation, development and control of shared representations.

While a detailed historical account of the interrelationship between Organisation Studies and Computing Science is beyond the scope of this paper, we observe that there are several sympathetic linkages concerning the development of these two fields.

Firstly, both fields became established in the third quarter of the 20th Century as multi-disciplinary applied sciences with significant military-industrial links (e.g. Locke 1989, Friedman & Cornford 1989). Secondly, albeit from different starting points in the Behavioural Sciences and in the Natural and Engineering Sciences, respectively, each field has constructed territories of interest which overlap. Historically, these have interconnected organisation and computation through information and have included areas such as cybernetics (e.g. Weiner 1948), industrial dynamics (e.g. Forester 1963), project management (e.g. Brooks 1975), human-computer interaction (e.g. Licklider 1960, Kay and Goldberg 1977) and user involvement in systems design (e.g. Mumford & Henshall 1979). Thirdly, from this basis, the mainstreams of both fields have come to address information as a medium that is coherent and manipulable, through which complex socio-technical or technical-social systems are able to be reliably engineered (e.g. Cooper 1987, 1991, Boland & Hirscheim 1987, Mouritsen and Bjørn-Andersen 1991).

But, the complex exchanges between these fields have become both more difficult and more misunderstood in a contemporary context of intensification. Through the pervasive, but equivocal processes of transition that surround what has been termed the *information society* (e.g. Webster 1995, Dutton 1996), not only have the computer-mediated portions of organised life become increasingly substantial and significant, but computerised media (particularly software) has also become a primary means by which increasing complexity is sought to be made manageable and reliable. As we shall explore in some detail, this articulates a paradox of complexity, whereby processes of expansion and extension of capacity (e.g. computerised organisational networking) coincide with their inherent limitation, through processes of increasing compression and equivocality. Thus making, for example, the integration of networked data and applications (i.e. interoperability) more problematic. Furthermore, much of the work that has addressed this complex, evolving territory has emphasised the controllability and coherence of the arenas of exchange between the fields, at the expense of their uncertainty and hybridity.

As a consequence, we concern ourselves with the problematisation of these exchanges, focusing, in particular, on structure and order in computer software in relation to manageability, risk and safety in computer-mediated organisation. We will explore the problematical nature of computerised information systems, the limits of manageability within these contexts and reflect upon the hybridity and uncertainty of processes of software development. From this basis, we consider two major areas of interconnection that are crucial to the complex relations between organisation, information and computation: the complexity of media and networks of exchange across computerised information systems; and the complexity of the interrelationships between Computing Science and Organisation Studies in articulating these exchanges.

A distinctive feature of our approach is that we address software not as a technological artefact with an assumedly pre-determined existence, but rather as text, open to a multiplicity of meanings. In these respects, our focus is on the media (i.e. software as text), rather than on the network, where the role of software in the creation of text (see Poster 1990 or the nature of information held within an electronic information system (see Mouritsen & Bjørn-Andersen 1991) has been examined. Considering software as text problematises its structure and order and brings us to examine the potentially chaotic nature of computerised information systems in contexts where manageability and interoperability are crucial. This is increasingly important in tightly coupled software systems where software itself can be the writers *and* readers of such texts, hence the paper examines examples of these circumstances.

In our view, the examination of the tensions between the manageability and unmanageability of electronic media develops a particularly fruitful avenue for interdisciplinary work on the relationships between organisation, information and computation. In pursuing this work we are aware of the breadth and complexity of this landscape of interconnection, the few relevant interdisciplinary explorations that have thus far taken place (e.g. Cooper 1991, Turner 1994, Coyne 1995) and the scale and significance of the territory that remains to be engaged with.

The paper is organised as follows. We open our discussion with a brief overview of Computing Science, aimed at those readers less familiar with this territory, and concentrating on the field's scope and concerns. This is followed by an examination of the organisation of information systems, conventional software engineering and our approach to software as text. We illustrate our approach with an accident involving software in a medical therapy system. This examination leads us to draw out significant linkages between Organisation Studies and Computing Science and we conclude by arguing that an appreciation of the heterogeneity and hybridity of these interconnections is essential for the development of forms of knowledge appropriate to the complexity of contemporary organised life.

Orientations

Computing Science is a heterogeneous field that is based around a Natural and Engineering Sciences core that extends to the Behavioural Sciences and Humanities (e.g. Van Leeuwen 1990, Dunlop & Kling 1991, Preece 1994). The fundamental concept in Computing Science is *computation* - the process of calculation and manipulation of data by computer. A primary concern of Computing Science is writing programs (i.e. software) in programming languages which when executed on a computer (i.e. hardware), manipulate data in ways which address particular problems. While the boundaries between the three strands of software, hardware, and data processing are now recognised as ambiguous (or even largely irrelevant), they are reflected in the early development of the field through the disciplines of Mathematics, Electronics, and Data Processing. Here, we concentrate on aspects of software, examining questions that, to an extent, are also reflected in hardware.

Software is composed of programs: a program is a finite representation of an algorithm (i.e. a method, or procedure for solving a particular problem) which itself is an abstraction of the needs or concerns of an operational world. Representations and levels of abstraction for problem domains are crucial to the process of problem solving and consequently to the complexity, predictability, and reliability of programs. Some of the major theoretical concerns in Computing Science are:
i) a (class of) program behaviour has some property; for example, a program terminates and delivers a solution.
ii) a program computes the solution in a certain number of steps; this articulates what is known as the complexity of the program.
iii) a program is consistent with its specification; that is, it is consistent with the description of what it should compute.

The first of these concerns is addressed as one of 'meta-theory'; the domain of questions such as what is computable and what are the limits of computation. These questions are sometimes expressed as solvability or decidability. One important example is known as the "halting problem": can one write a program that decides whether or not class of programs always terminates and delivers a solution? Perhaps unusually for a relatively young science, the meta-theory is very well developed, partly because it actually pre-dates electronic computers by some 30 years as a branch of Mathematics. One of the founders of this field was Alan Turing, his most famous result being an elegant demonstration, through what is now known as the "universal Turing machine", that the halting problem is *not* solvable.

The second and third of these concerns are addressed as within the 'theory' of Computing Science. Whereas the meta theory focuses on essentially negative results (i.e. establishing the limitations of computation), the focus of the theory is to deliver positive results about how computation works in practice (i.e. in the framework established through the meta-theory). Important issues here include, what is the complexity of a computation, how should the problem domain be represented as a computation, does the program reliably solve the problem that was intended, and is the level of abstraction appropriate? For example, it may be established that a problem is computable from the meta theory, but the complexity might not enable the computation, or even predictions about the computation, to be carried out within a given timescale. Furthermore, appropriate criteria for judgements about the reliability and predictability of programs also need to be established.

These latter concerns are particularly problematic and have became increasingly prominent since the late 1960's, coinciding with the advent of third generation computers requiring the implementation of large software systems, and the extension of computation into new areas, such as avionics, aeronautics and medical therapies. An important landmark was the recognition that software, like hardware, also needed to be *engineered*. The field of software engineering has since become a substantial arena of theory and practice with design principles, methods, methodologies, strategies, policies and tools which aim to aid the production of software which is reliable, maintainable, efficient, and usable (see, for example, the numerous editions of Sommerville's standard texts, from 1982 through to 1996, and Pressman 1992). While substantial, the arena is both still developing and inherently multidisciplinary. For example, at one extreme its activities include using mathematical methods and automated theorem proving tools to prove consistency of program and specification (e.g. see Thomas 96, Clarke and Wing 1996). At the other extreme, it includes consideration of the human and sociological factors of the usability of software as supported by the human-computer interface, and software development such as the cognitive psychology of programming, (e.g. see Preece 1994, Ehn 1991).

Information Systems in an Information Society

One of the major factors in the extension of information systems across contemporary organised life has been the increasing use of software in the management of complex systems in which a failure would pose a serious threat to human life, both directly or indirectly. Examples of such systems include aircraft control, air traffic monitoring, medical process monitoring (e.g. continuous drug delivery), medical treatment equipment (e.g. radiotherapy), control systems for chemical and nuclear power processes. There are numerous advantages to using software in such 'safety-critical' applications, since software can be flexible and easily adapted, a wider range than purely electro-mechanical conditions can be monitored and physically small and reliable computers are involved. Moreover, such software can allow the introduction of strategies which reduce the amount of time humans need to spend in particularly hazardous situations. In these circumstances, 'safety-critical' software plays a pivotal mediating role between human users and electro-mechanical components in complex hybrid systems.

However, studies of accidents and breakdowns in complex hybrid systems across a broad range of organisational and cultural contexts (see, Turner 1978, Perrow 1984, Toft & Reynolds 1994) have exposed how large-scale system breakdowns (e.g. 'disasters' such as the Clapham rail crash in the UK) result from the interrelationship and development of small-scale problems in unanticipated ways. Two significant and interlinked issues are raised by these analyses. Firstly, all complex hybrid systems are thus to some extent 'safety-critical', where the consequences of failure are more or less catastrophic (e.g. from the loss of an airliner due to the breakdown of an air traffic control system, to the loss of student grades due to the breakdown of a data-processing system). Secondly, in such complex hybrid systems, the management of risk (i.e. the achievement of appropriate levels of safety) should be understood as both an important need and a problematic objective (see Sagan 1993, Beck 1994).

These issues are central to the examination of software, since it has become the primary means by which complex hybrid systems are connected, extended and dispersed (e.g. the networking and dissembling of organisations), as well as the primary means by which increasing complexity and ambiguity is sought to be made manageable and reliable (e.g. safety-critical process control). This tension articulates a paradox of complexity which goes to the core of debates surrounding the nature and form of organised life in an *information society* (Lyon 1988, Lyotard 1991, Bauman 1993). Consequently, computerised information systems need to be addressed as media which intensify the complication of contemporary organised life whereby the expansion and extension of capacity coincides with its inherent limitation, through processes such as the increase of ambiguity and compression. Under these circumstances, as Lash & Urry (1994) argue, contemporary organised life is characterised by the intersection of order with disorder in an unstable and contingent world.

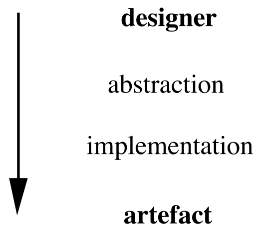
The relationship between computerised information systems and the process of transition in complex organisation has been an increasing concern for Organisation Studies, particularly over the past decade. A considerable body of evidence has been accumulated and examined, and computerised information systems have become understood as both the catalyst for and the medium of contemporary organisational transition (e.g. Zuboff 1988, Scott-Morton 1991, Kocham & Useem 1992, Rhodes & Wield 1994, Fincham et al 1994, Boddy & Gunson 1996). Whilst the frame in which these matters have been addressed has primarily emphasised the significance and manipulability of computerised information systems for the strategic process of organisational innovation (see Galliers 1995), the literature gives substantial evidence of widespread failure to achieve these desired outcomes. The problematics of achieving innovative success through computerised information systems have been primarily understood as an issue of implementation (see Myers 1994), where tensions between systems design and organisational needs are ultimately worked through. Whilst the socially constructed nature of these processes of exchange between the arenas of computation and organisation in the articulation of these tensions is acknowledged (e.g. Orlikowski 1992, Walsham 1993), the conclusions of the Organisation Studies literature in response to these tensions are clear: that the earlier and the more substantially systems design can be integrated into the process of strategic organisational planning the greater the likelihood of achieving innovative success (e.g. Ward & Griffiths 1996). Thus, this recent engagement of Organisation Studies with Computing Science around their linked concern for the design and implementation of computer-mediated information systems has emphasised strategic control (over both process and product) but overlooked the inherent problematics of software and the limits of such manageability.

Consequently, both within and beyond the Behavioural Science core of Organisation Studies, the transformation of organisation by and through computerised information systems has come to be addressed as a process of change which is either largely utopian (characterised by innovation, devolution, synergy or empowerment, e.g. Maddison & Darnton 1996, Blackler 1995) or largely dystopian (characterised by exploitation, divestment, surveillance, or management through blame, e.g. Bloomfield & Coombs 1992, Knights & Murray 1994). Indeed, in terms of broader debates, computerised information systems have become addressed as being able to extend the boundaries of the manageable in the turbulent complexities of an information society, either through facilitating more interactive and egalitarian forms of organising (e.g. Mulgan 1991), or through facilitating the refinement and spread of exploitation and organisational surveillance (e.g. Lyon 1994). Yet, both of these understandings of transition, whether oriented towards empowerment or exploitation, concentrate on issues of organisational form and behaviour in the implementation of computerised information systems (e.g. types of network), whilst assuming the form and behaviour of the media (e.g. computer software), which makes such networking possible, to be clear, coherent and controllable.

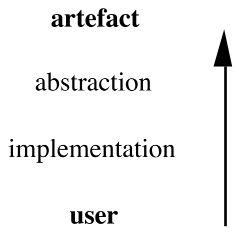
However, such either/or analyses are misleading, because they both oversimplify and understate significant problematics: firstly, of the complex interrelationships between information, computation and organisation; and secondly, of the electronic media through which these interconnections are made and remade. Computer software (and hardware) does not always behave in reliable, or predicted ways, as the Pentium processor 'bug' (Pratt 1995) and the Therac-25 accidents (Leveson & Turner 1993, Thomas 1994a,b) illustrate. Furthermore, as software becomes more pervasive and complex, providing new forms of computer-mediated organisational control and extension in more distributed contexts and encouraging more tightly-coupled complex systems, the understanding of problems of manageability in computer software becomes more urgent. Moreover, ongoing investigations of recent software-related disasters in complex systems (e.g. AT&T long distance network 1991, London Ambulance Service 1993, London Stock Exchange Taurus 1993, Denver Airport baggage handling 1996) show how the failure of software, software project management, and interoperability have all been contributory factors to systems disasters. Unfortunately, these problematics have been largely overlooked within Organisation Studies, leading Leveson (1995, pg.63), to observe that "with the introduction of computers into the control of complex systems, a new form of complacency appears to be spreading - a belief that software cannot 'fail' and that all errors will be removed by testing". In the next section, we consider the engineering processes for software.

Software as Text

Software engineering has produced numerous generic and domain-specific process models of developing software, the most widely-used of these are variants of the so-called 'waterfall model' (Sommerville 1996). While the stages, and progression between stages, depend on the particular model, the essential aspects can be summarised as: requirements analysis (abstracting the behavioural requirements of the software and any constraints or relevant context), specification and design of abstract models (developing abstractions of how the software will behave, the constraints or context; how the problem will be partitioned and design of the solutions), implementation and testing (representing and implementing components of the solutions in a programming language; testing and integrating the components). We summarise this as a process of abstraction followed by implementation:

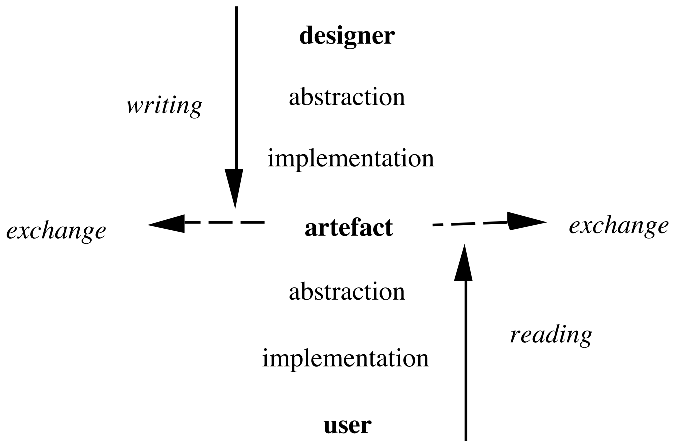


While the stages are conceptualised as distinct, in practice, they may overlap and feed back into each other, and in any non-trivial software development, the process is not strictly linear since the movement between the stages can take various forms: from transformation and iteration to refinement and rupture. However, by organising the development stages of any process model in this way, the complexity of the software system is sought to be managed. While such models have been developed since the conception of software engineering, and have remained prevalent until recently (see Coombs & Hull 1996), for some time little attention was paid to the artefact after construction, save for maintenance. That is, the use of the software was neglected until when, within the field of human-computer interaction, it was recognised that "the problem is to design the system so that, first, it follows a consistent, coherent conceptualisation - a design model - and, second, so that the user can develop a mental model of that system - a user model - consistent with the design of that model" (p.46, Norman 1986). This latter process is summarised below:



While the design-focused, traditional software engineering process is primarily one of *writing*, the user-oriented process is essentially one of *reading*. Indeed, post-structural theories of philology (e.g. Derrida 1984, Knoespel 1991, Poster 1990), indicate that we should be as concerned with how texts are read, as with the writing of them. With this in mind, a crucial issue for software engineering becomes how a text works for a variety of writers *and* readers, bearing in mind that the textuality of software is rich and complex: the languages used at each stage range from natural language, tabular and graphical notations, to mathematics and formal programming languages and machine languages.

Furthermore, while the fields of human-computer interaction and programming methodologies have made explicit the concern for the *human* user, this has been at the expense of concerns for other forms of user, e.g. other software systems and electro-mechanical devices. However, this form of "user" is becoming increasing important, with the increasing prevalence of tightly-coupled software components in complex computer-mediated systems. These tightly coupled components also assume the roles of writers *and* readers; for example, an software system in a "fly-by-wire" aircraft which reads data from set of electro-mechanical sensors, will write that data to an onboard flight control system which will read the data and make appropriate adjustments (e.g. to engines and wing configurations). So while such users do not form "mental" models, embodied within the software must clearly be a model of what it is being "read".



With texts thus open to a multiplicity of interpretations and software operating as a multilateral medium of exchange, a software artefact can thus have no complete and stable meaning. Conventional software engineering can thus be regarded as a 'grand' explanatory narrative (Norris 1982) which addresses the text as a 'bearer of stable (if complicated) meanings and positions the interlocutor as seeking to render the text predictable and controllable. It is a project of managing risk that seeks to unify and explain a complex system (i.e. making order) through a process of totalisation (i.e. eradicating disorder). In contrast, a post-structural approach to software as text leads us to consider how behaviour (e.g. 'normal' and 'abnormal') affects the mode and content of data, and hence the information it carries within a complex system (i.e. organisation) of which it is a constituent. We argue that recognition of these roles, exchanges, and the multiplicity of meanings attached is vitally important when software is used in safety-critical or high-risk situations. In the next section we focus on the significance of failure and breakdown in complex, hybrid systems.

Safety in Computer-Mediated Systems

We earlier outlined a paradox of complexity for computerised information systems where software may increase the safety of such a system, but it will also increase the complexity of the system and hence increase the associated risk. In this section, we examine an example of such a hybrid computer-mediated system. (We recognise, of course, that software alone cannot pose a threat to human life or the environment; it is the embedding system breakdown – resulting in a hazardous hardware operation – which ultimately poses the threat.)

While there have been various fatal breakdowns in complex systems involving safety-critical software (see Leveson 1986, Mackenzie 1994), the most serious civilian deaths to date attributable to malfunctions of safety-critical software are the Therac-25 computer-controlled linear accelerator accidents (Leveson & Turner 1993, Jacky 1991). Linear accelerators are used for medical radiation therapy (e.g. in cancer treatment) and the accidents we refer to involved the delivery of sometimes fatal overdoses to patients in medical clinics in the U.S.A. and Canada during the late 1980's.

The danger of radiation overdose in a dual-mode design linear accelerators (such as the Therac-25) has long been acknowledged, at least since 1966 when there was such an accident involving a non-computer controlled machine at Hammersmith Hospital (BMJ 1966). Since then, most machines have contained some safety system of hardware interlocks. The Therac-25 was not the first computer-controlled linear accelerator, but re-used much of the software developed for its predecessor, the Therac-20, which was also computer-controlled. However, the Therac-25 was unique in that it was entirely software controlled: there were no hardware interlocks. A consequence of this system design was that while certain 'abnormal' software behaviour in the Therac-20 would result in a blown fuse, the same software could have an entirely different and more damaging effect in the Therac-25.

Of course while accidents in such complex systems cannot be simply attributable to one error in the program behaviour (i.e. system accidents stem from complex interactions between the various software and hardware components), it is instructive to consider one particular software error which contributed significantly to the accidents. The example involves the keyboard handling software, that is the software controlling the way in which the operator entered and edited the treatment parameters. This included information about the type of treatment (electron or X-ray therapy), the intensity of electron beam, the positioning of beam, etc., and was entered on the screen at the computer terminal. If the operator made a mistake when entering the treatment data, the operator could edit parts of the data on the screen, instead of re-entering all of the data from the beginning. As a consequence of a software error, it was possible (under very rare and unforeseen circumstances), for the operator to appear to edit the data, i.e. the corrected values for the treatment parameters appeared on the screen, but the control process ignored these values and continued with the (erroneous) values which were originally entered[1]. The result of this process was that patients could and indeed were delivered incorrect, and sometimes fatal radiation doses. To summarise, software previously understood to be benign, when embedded in a *new* system entailed a different and sometimes lethal behaviour.

This accident is particularly significant because it raises problematic issues regarding the interconnection of organisational and computational perspectives in addressing the manageability of complex hybrid systems. On the one hand, we ask to what extent Computing Science, and software engineering in particular, acknowledges the ambiguities inherent to the textual process of software engineering; on the other hand, we ask to what extent Organisation Studies acknowledges the problematic and uncertain nature of software behaviour in computerised information systems. Indeed, so strong was the 'belief' (both organisational and computational) in the safety-critical software of the Therac-25, that even after the first few accidents, the software was not investigated, as it was not considered possible for it to possess hazardous behaviour (Leveson and Turner 1993).

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[1]The particular circumstances under which this was possible are not relevant to our discussion, but they concerned the elapsed times between edits.

Subsequent analyses of the Therac-25 software (e.g. Thomas 1994a,b) have used mathematics, and software embodying mathematics, to reason about the behaviour of software and the software development process. Whilst undesirable (and consequently dangerous) properties of the software were shown to hold, the analysis took place after the accidents, when some of the software development problems had already been identified. Of course the fact that the analysis was post-hoc does not mean that it could not have carried out before the fact, but it must be noted that many organisations cannot, or do not support this kind of analysis. This is, in part, because this kind of analysis is enormously time consuming and involves a high degree of expertise and would not be feasible, in general, for an entire large scale system, except when targeted at 'high-risk' components. Thus, not only does the (problematic) capacity to identify such components in advance becomes crucial, but moreover, one can only formally (or otherwise) analyse the properties which one has had the foresight to determine. And while there are numerous generic properties which are recognised in software engineering, inevitably crucial properties which impact on the safety, or reliability of a system, are unique to that system. Thus, identification of these properties is as crucial (and as problematic) as identifying the high risk components.

It is also arguable whether the results of a precautionary analysis would have been interpreted in such a way as to prevent the accidents; such an interpretation may require what have recently been called the 'extra-logical' factors involved in complex software engineering. As we have already suggested, the reading/writing relationship between formal models and operational models is crucial here, as are the series of multilateral exchanges between designers, verifiers, manufacturers and users, interconnected by the performance of physical components.

In a pioneering study of 'man-made' disasters, Turner (1978) argued that accidents have an 'incubation period' in which a series of events running counter to established beliefs about the way in which the system operates remain unnoticed. The period of order ends when some event(s) draws attention to the discrepancy between the system as it is believed, and as it is operating, resulting in a sudden shift in information levels. The Therac-25 accidents illustrate these translation, or migration issues well: the (errant) software behaviour in the Therac-20 went unnoticed (although its' effects were potentially observable, e.g. as blown fuses) until the code was reused in the Therac-25 when it directly affected patients in adverse and fatal ways.

It is interesting to note that another spectacular (though not fatal) illustration of the textuality of software, and particularly software as both reader and writer, occurred more recently with the explosion of the Ariane 5 rocket launcher in June 1996 (European Space Agency 1996). Briefly, the flight control system for the Ariane 5 included much of the software developed for the Ariane 4 (its predecessor). Shortly after take-off, the horizontal velocity of the Ariane 5 exceeded the upper limits of an internal software variable; these limits had been defined according to the requirements of the Ariane 4 (and were never exceeded during the operation of the Ariane 4). The result was an 'overflow' error in one of the inertia reference (software) systems. This error was then transmitted to the flight control system where it was interpreted, not as an error message, but as flight data, since this software was not expecting to "read" such an error message. Consequently, the flight control system set the engines and boosters according to this (bogus) data, resulting, shortly thereafter, in an explosion due to the impossible aerodynamic forces.

While limitations and uncertainties concerning the use of analysis methods have become accepted (see Leveson 1995, e.g. human ability, applicability of abstract system models, consistency of theories, tool quality and availability, notation quality, process maturity, evidence of success and management pressure, to enumerate but a few); we further suggest that software engineering has not yet developed an adequate framework for understanding the reliability and manageability of software, particularly given the complexity of exchanges between the heterogeneous elements of contemporary computerised systems (see also Law 1994, 1997). In these respects, there are two general conclusions for software engineering which can be drawn from our consideration of the textuality of software and its relationship with contemporary organised life. Firstly, since accidents in organised contexts that have been mediated by safety-critical software appear to be 'normal accidents' (Perrow 1984), resulting from the unforeseen interaction of different components and activities in a complex hybrid system; we may deduce that whilst software may contribute as a cause, such accidents must be beyond the discrete control of the software. Secondly, from the above flows the understanding that the inadequacy of software is not a problem which could be solved by additional resourcing (i.e. scale, time, etc.) or enhanced sophistication (e.g. ever more grand and inclusive parameters of engineering), since it is the engineering approach to the management of software and not the particularities of each case which requires attention. In quantum (i.e. post-structural) science, where order and disorder are understood as created simultaneously (see Prigogine 1989, Coveney & Highfield 1995), codification must be associated with unpredictability: hence, we cannot achieve the design of absolutely error-free software, or even the zero-fault designs described by Gaudel (1995). There can thus be no single 'grand narrative' role for software engineering and we have, in essence, an incompleteness result.

Our consideration of the conventions of software engineering has already suggested numerous sympathies with the orthodoxies of Organisation Studies, however, these relations need to be considered in the context of the heterogeneity of these fields. Following our earlier discussion of the shape of Computing Science, we now turn our attention to Organisation Studies, in the context that recent attention (e.g. ESRC 1994, Burrell et al 1994) has also established the broad parameters of this discussion, that Organisation Studies is based around a Behavioural Science core that extends to both the Humanities and Sciences.

Information and Manageability

Histories of the development of Management and Organisation Studies across different countries and continents (e.g. Locke 1989, Engwall 1992) have pointed to the significance of the third quarter of the 20th Century when the field became established in Higher Education (predominantly through departments of Engineering or Economics). At the same time, a mainstream of theory and practice was developed which became formalised (or canonised) in terms of the orthodoxies that have recently become the focus of deconstruction and reorientation (e.g. Alvesson & Willmott 1996). This phase has been termed the 'new paradigm' (Locke 1989), during which the theory and practice of Organisation Studies became positioned as both truthful and useful and sought to become an established 'applied science', like Law or Medicine. Characterising this process was the synthesis of earlier established disciplines (predominantly Economics, Engineering and Psychology) in the formation of a body of knowledge that was authoritative, ubiquitous and readily translatable to the professionalising practice of managing in a diversity of circumstances and contexts.

However, following Foucault (1974), this process of formation needs to be understood as essentially constitutive, through which the world as viewed and the viewing of the world intersect to construct and complement each other (see Cooper 1992, Kallinikos 1996). Hence the 'new paradigm' of Organisation Studies was a distinctive formation which, on the one hand, constructed a quasi-scientific frame for the integration of social and technological sciences concerned with the systematisation of the behaviour of both people and technologies, and on the other hand, represented organised life as composed of discreet, coherent and manipulable components which were interacting in a complex, changing but ultimately manageable world (see Cooper 1986, 1989, Clegg 1990). This highly problematic double synthesis (managing tension within and between multi-disciplinary behavioural science and multi-contextual organised life), constituted Organisation Studies as an archetypally modern 'applied science'. In other words, a field that is characterised by the heterogeneity, division and disorder of the modern condition, which, at the same time, is predicated upon the ordering and management of this very condition through its theory and practice (see Jeffcutt 1995).

Such a problematic symbiosis between modern science and the modern world, has become increasingly significant to the Human (or Behavioural) Sciences and particularly to their experience of dis-location and re-orientation over the past decade or so (see Geertz 1983, Polkinghorne 1988). Based on his analysis of Anthropology as a form of ordering, Friedman (1994) argues that distinguishing the modern development of the Human Sciences has been the search to convert difference into essence. Such essences could then be hierarchised and homogenised in the organisation of the centre, enabling modern forms of order to thus become characterised by a unity and coherence. However, this formation produces an apparent or putative order that is made out of and managed from division and difference. Hence the codes which make up modern order need to be addressed as effects of a play of difference, translated into and represented as a hierarchy of essence (e.g. stabilisations of dominance and subordination) which is understood as in a dynamic state of becoming (i.e. working on and through an incomplete present towards a better future). Thus the dynamism of modern order is also an effect of the play of difference, articulated as a dialectic of transcendence (e.g. grand theories and projects of progress), which should proceed through tension (e.g. conflict and contradiction) to resolution. As a consequence, modern order becomes defined in terms of fundamental tensions, for example, between liberty and discipline (Wagner 1994) or structure and process (Cooper & Burrell 1988), however, these tensions are represented as in a process of motion (i.e. progressive or reforming modernisation) towards a state of resolution. Notions of organisation and management are thus integral to this sought for reconciliation of the play of difference in both modern selves (Hoskin 1995) and in modern society (Jaques 1996). However, as the theory and practice of organisation has become a more explicit (even vanguard) component of the process of modern ordering (i.e. in its 'new paradigm'), it has become increasingly clear that Organisation Studies has been incapable of achieving these striven for reconciliations. Indeed, the field has become characterised by a restless and increasingly desperate searching for ever more novel meta-narratives of revitalisation for its theory and practice (such as TQM or Re-engineering, see Munro and Hatherly 1993, Grint 1994).

These tensions are significant for the understanding of the interconnections between Organisation Studies and Computing Science and have become particularly evident over the past decade. We have already argued that such tensions had historically been managed by the sympathetic construction of overlapping territories of interest through which mutual goals of constructing, maintaining and applying abstractions could be exchanged. From this basis, we observed the mainstream of both fields to have come to address information as a medium that is coherent and manipulable, through which complex socio-technical or technical-social systems could be reliably engineered. However, we also noted a contemporary context of expansion and intensification through which greater demands and pressures had been placed upon the sympathetic exchanges of this interrelationship. As a consequence, the considerable attention given to computerised information systems in Organisation Studies over the past decade has emphasised two interlinked strategic questions: firstly, the management of socio-technical transition in a context of risk through computerised media, and secondly, the management of cross-disciplinary relations with Computing Science in the construction of software and hardware.

As we have seen, the products of this recent process of intensified interconnection have articulated contemporary organised life in forms which seem strangely familiar. For the contemporary 'knowledge work' of socio-technical networks mediated by computerised information systems, whether understood as oriented towards empowerment or exploitation, appears to entail a number of significant translations and revitalisations:

i) a hierarchical model of organizational communication which emphasises a master system for the coding and decoding of information would seem to have become translated into the extended capacities for information processing of the networked organization. This revitalises the authority of a central managerial authority for the co-ordinating and controlling of organizational complexity.

ii) the understanding of technology as an intrinsically neutral medium for the extension of human capacities would seem to have become translated into computerised information systems as the medium of sophisticated but controllable organisational change. This revitalises the authority of complex organisations as vehicles of progress in a turbulent and uncertain risk society.

iii) the structuring principle of core and periphery appears to have become translated into both the reconfiguration (i.e. disassembly and reconnection) and extension (i.e. globalisation) of complex organisations through computerised information systems. This revitalises the centrality of the core and the power of the centre in the policing and adjustment of the networks' boundaries and margins.

These features are familiar because they represent a process of (attempted) resuscitation of an 'old' order (i.e. organisational coherence and manipulability) through yet another novel persuasive form. Computerised information systems and the manageability of electronic media thus articulate Organisation Studies search to regain mastery over its viewing and viewed worlds in the face of contemporary disturbances and dislocations to its established theory and practice. However, we have suggested that there are not only problems with this process of renewal in general (i.e. the ultimate impossibility of such modern quests), but also with this meta-narrative in particular. Indeed, for 'giants' to be able to 'learn' (i.e. control, Kanter 1992) the flexible dance of networking through computerised information systems, they need to be stabilised on relatively solid ground and their diverse and disaggregated elements need to be manipulably interconnected through a central nervous system. Yet such presumptions of coherence and groundedness are clearly unrealistic in an information society, characterised by the explosive pluralisation of subjectivity, interconnection and artefaction. As Lyon (1988), Baudrillard (1988), Lyotard (1991) and Bauman (1993) argue in their different ways, such processes form a hyperreal marketplace of semiotic exchange where information becomes the transient medium and message. Hence, in the context of rapid, multiple transactions through a panoply of communications media (e.g. information highways and byways), between a multiplicity of dispersed transactors (e.g. producers and consumers), the characteristic features of complex organisation, such as control, consistency and stable bounding, become both problematic and ephemeral (see also Boisot 1995). Indeed, as Boland (1987) argues, underpinning the contemporary development of computerised information systems in the extension of complex organisation and the renewal of Organisation Studies have been significant oversimplifications of the nature of information which he describes as 'fantasies'.

Firstly, the assumptions of a master system for the organisation of communication requires both the transparency of meaning and a central, determining authority. However, as we considered in the design of safety-critical software, a totalizing master narrative is unreachable with information as a translation process of mutually constituting exchange and representation.

Secondly, information systems cannot be assumed to be solely predisposed towards the extension of progressive human control over a threatening periphery. Indeed, electronic media, like other technologies, are not intrinsically neutral extensions, but complex systems of mediation and representation which interact in the hybrid constitution of an information society, where, as in the case of the Therac-25 and Ariane 5, meaning migrates.

Thirdly, under these interconnected strains and in spite of policing and surveillance, the organisational centre will not be able to hold on to its conventional pre-eminence and mastery. Hence, through a process of radical pluralization, multiple, simultaneous centres of ordering inevitably emerge, articulating both local and worldly contingencies, as the shaky, stumbling and safety-critical nature of contemporary organised life emphasises.

The contemporary transition of organised life through computerised information systems cannot then be simply characterised as either empowering or exploitative, since these are conventional analyses which rest on either prioritising a 'managerial' orthodoxy or overturning it with a 'critical' alternative. Instead, contemporary organisational transition needs to be approached as both empowering and exploitative, rather than either/or. As such, electronic media have both rewritten the contemporary labour process by shifting access, patterns and places of work (e.g. remote tele-working) as well as translating established sexual divides (e.g. the gendering of new technologies, see Cockburn 1991). Equally, whilst computerised information systems have become extended through an infrastructure (e.g. the internet) which has pluralized and dispersed access (both local and global), at the same time organised life has become further socioculturally and spatially divided as its flows have translated risk society into relatively 'wild' and 'tame' zones (see Lash & Urry 1994).

Furthermore, computerised information systems are paradoxical in terms of both medium and message: for their very scale, speed and complexity leads to the organisational processes they seek to inscribe and order becoming effectively unaccountable and unmanageable. For example, the patterning of international financial markets (interconnected through the Internet) could only be approached as chaotic: characterised by an unruly order that is discontinuous, incomplete, unpredictable and unregulatable, which articulates sustained growth as well as spectacular falls (e.g. 1989 Crash, Black Wednesday, Barings, etc.). Moreover, the very complexity of these heterogeneous and hybrid computer-mediated networks enables new subversions, such as hacking and viruses, as well as new deficiencies, such as software 'bugs' and 'crashes', alongside any extension of capacity.

In relation to these expanding problematics in the computer-mediated forms of contemporary organised life, we examined the development of safety-critical software engineering. However, despite the considerable focus on techniques of proof and the formalisation of methods and standards, we questioned the ability of this approach to achieve such error-free outcomes. As our analysis of the Therac-25 accident has shown (see also Leveson 1995), software controlled systems can fail due to errors that are both generated by unspecified implementations of, and unspecified interactions within, the specified system. In other words, such computerised information systems can generate errors as part of their normal activities which are both beyond their operational parameters and beyond any human or non-human intervention. The implications of these cases are significant, because they concern complex computer-mediated and controlled systems that have been carefully engineered (i.e. designed and tested) to be closed and complete, which, through their complex heterogeneity, interactively generate incompleteness and develop unspecified aspects of their process. Moreover, these cases exemplify the interconnection of 'indeterminacy' with 'diversity', the two defining characteristics of the process of organising described by Cooper & Law(1995).

Approaching the Un-modern

The broad significance of our investigation of the nature and form of software in computerised information systems is that it examines aspects of the interrelationships between organisation, information and computation that have been both under-recognised and under-explored. We considered Computer Science and Organisation Studies to be interconnected through information, exhibiting both mutualities and differences, but found the nature and form of these exchanges to be crucial, particularly in relation to questions of decidability and manageability.

On the one hand, where the interrelationship between organisation and computation through information was articulated in terms of a *dialectic of transcendence*, the form and behaviour of the electronic media through which this transcendence was sought to be managed was largely overlooked (e.g. in the literature on the strategic implementation of computerised information systems). We suggested this had been so because of a concentration on computerised information systems as representing a master code (or meta-narrative) which was discrete, coherent and manipulable with no theoretical limits to manageability. Consequently, the privileged medium of extension for complex systems, computer software, had to be theorised as homogenous, indivisible and neutral, since the role of the medium was to manage order from incoherence through the consumption, conversion and co-ordination of difference. Hence, the textuality of computer software, such as the multilingual and reversible process of exchanges by which we observed the medium to evolve and then to work across time and contexts, could not be recognised. Similarly, the inherent hybridity and instability of computerised information systems in the semiotic exchanges of an information society could neither be addressed.

On the other hand, where the interrelationship between organisation and computation through information was articulated in terms of a *dialogic of transgression*, the form and behaviour of electronic media was largely underexplored in a concentration on the socio-cultural processes of computing (e.g. Star 1995, Dunlop & Kling 1996). We thus considered our analysis of the hybridity and provisionality of software as text as analogous to Cooper & Law's (1995) reading of organised life as composed of heterogeneous networks of humans and non-humans shaped by the dynamic transactions of randomness and code. Whilst the concentration is again on systems of information, these understandings emphasise difference, hybridity, under-determination and instability in a process of 'cyborganisation' (see also Haraway 1991). Media of translation and exchange between heterogeneous elements are of course crucial to complex cyborganised systems, such as the software mediated systems we have been considering in this paper. However, we would contend that by the inherent incompleteness and undecidability of such media, the cyborganisation process must be beyond both human (e.g. regulatory structures) and non-human (e.g. software) forms of control. In these circumstances, the limits to manageability are ambiguous, shifting and reversible, making ordering become patterned but not predictable (i.e. chaotic in the scientific sense) and plural but not compatible (i.e. unmanageable in the conventional sense).

From this basis, the unbounding and pluralisation of contemporary organised life needs to be addressed as not symptomatic of an information society which exceeds modern order (i.e. a newly disordered and untamed condition), but, rather, of an instability that is implicit and unable to be exceeded (e.g. Lyotard 1991), where order and disorder are mutual processes (e.g. Prigogine 1989). Contemporary organised life thus needs to be understood as ordered by a deconstructive and metaphorising reflexivity in which the incompleteness of hybridity and the ambiguity of heterogeneity are both inherent and unavoidable. These conditions do not mean that organisation is unable to take place, only that there cannot be a single, dominant centre - but rather a series of multiple, simultaneous and partial nodes; likewise, there cannot be a complete, controlling code unfolding through a unified narrative - but rather a series of discontinuous, incomplete and incompatible patterns. Hence, what occurs at the relational interstices of nodes and patterns is organising, however this is as much being managed by, as the managing of, particular interconnections. This dynamically hybrid process of transition is also paradoxical - being multilayered and multifaceted as well as partial and incomplete: accordingly, the ordering that is made (i.e. the bounding, forming and shaping of interrelationships) is necessarily temporary and transitory, since through heterogeneity and incompleteness these arrangements will always become unbound and reshaped ... and so on. In short, we are irretrievably part of an un-modern process of organising that is intertextual, fuzzy and in a perpetually subversive state of motion, in which media (particularly computer software) have both constitutive and transgressive effects. Cooper and Law (1995) articulate these processes of organisational flows as follows: "that everything is in a state of both tension and motion; and that if matters are more or less stable for a moment, then this is, indeed, an achievement; an outcome achieved in a series of reversible translations" (p.264).

Consequently, the main finding of our examination of the interrelationships between organisation and computation is that the engineering of modern organised life needs to be recognised as theoretically and practically unreachable, since information has to be understood as ultimately unmanageable. For the mainstreams of both Organisation Studies and Software Engineering, we have suggested the appropriateness of a reorientation of these interlinked fields of 'applied science' towards the development of more modest, situated and dynamic understandings of information (i.e. from the dialectics of transcendence to the dialogics of transgression). We would thus like to conclude by briefly reflecting on aspects of ongoing processes of reorientation in these fields, where some significant differences are becoming evident.

On the one hand, this process of reorientation problematises the theory, rather than the meta-theory of Computing Science. As limits to the manageability of software have become articulated, some reorientation of software engineering towards the need for different approaches to different problems in computerised information systems has been taking place: for example, the role of software may be scaled down rather than scaled up, limiting applicability to restricted domains. As the software lifecycle becomes compressed (delivery in 2 days is now more often the case than 2 months), so it also becomes replicated and extended, requiring a shift of resourcing from writing activities towards reading activities. Our particular emphasis on textuality, migration of meaning, trajectories of ordering and practices of learning to work with the increasing complexity and hence risk associated with the reuse of software is increasingly urgent. Reuse (like the cases of Therac, Ariane) is becoming more prevalent with very few computerised systems being built from 'scratch', the majority being built upon existing systems. However, there are no calls to abandon process models and methods for analysis software and processes, or to give up on safer software, just because there is no complete solution. Rather, research needs to become focused on how to target techniques on crucial activites and artefacts (little narratives), as well as process models which acknowledge 'inherent uncertainty', with respect to design and operational behaviour (e.g. Littlewood et al 1996). An example of these needs becoming recognised is the recent EPSRC (the UK Engineering and Physical Sciences Research Council) initiative which sponsors interdisciplinary research in systems engineering. Another is the UK Defence and Aerospace Foresight Panel's inclusion of requirements engineering, systems integration and reuse as key issues (Foresight 1997).

On the other hand, this process of reorientation problematises the meta-theory of Organisation Studies, which addresses the limits to manageability, where it is maintained that organised life is always ultimately manageable. Yet, as this orthodoxy has become progressively exposed (particularly over the past decade), the canon of Organisation Studies (i.e. the mainstream articulations of the meta-theory) has become rewritten, revitalised and extended. This process of putative renewal has been achieved by the consistent generation of a series of ever more novel meta-narratives (e.g. Corporate Culture, TQM, re-engineering) each of which have articulated progressive technologies and forms of 'subjection' for the revitalisation of socio-technical systems (see Munro and Hatherly 1993, Ezzamel et al 1994), as well as novel and persuasive readings of organised life which synthesise cross-disciplinary insight for the revitalisation of the mainstream of theory and practice (see Jeffcutt 1994, Grint 1994). The ultimate manageability of contemporary organised life through computer-mediated and managed information systems has thus become the latest of a succession of such meta-narratives, each of which, since they promise to achieve the impossible, has inevitably become superseded. But, this process of succession engages with the problematics of reorientation as a question of theory and thus avoids the recognition that the matter of the limits of manageability really needs to be addressed as a question of meta-theory. Accordingly, the ability of Organisation Studies to become reoriented towards more fruitful avenues and forms of development (e.g. neo-disciplinarity and 'managed enough' organising) requires both engagement with meta-theoretical questions of the limits of manageability[2] and the interruption of the sterile process of performative succession for the mainstream of its theory and practice.

We recognise that the ideas which have interconnected to inform these un-modern understandings of organisation, information and computation have travelled from different directions; on the one hand, from the Humanities, language as comprising contingent interrelationships that are both constitutive and subversive (following Derrida); on the other hand, from the Natural Sciences, mathematical and physical relationships as being incomplete, undecidable but patterned (following Godel). Hence, where post-structuralism and chaos theory cross-connect, can be found the conditions for an un-modern understanding of electronic media in the process of organising (e.g. Turner 1994, Cooper & Law 1995, Coyne 1995). However, this paper is not only arguing for the fruitfulness of a dialogic process of exchanging and interconnecting different ideas (e.g. intertextuality and undecidability) in an evolving interdisciplinary space, but also that such a contact zone (Pratt 1992) is an essential move towards appreciating the complexity of the interconnections between organisation, information and computation. In other words, this is a territory that is necessarily transdisciplinary and transcontextual, articulated through subtle and fragile exchanges between ideas and practices that cannot be conveniently reduced and separated into discrete theoretical or practical arenas. Hence, the challenge for un-modern enquirers after knowledge in this arena is to build syncretic dialogues which recognise both mutuality and difference, developing a heteroglossic territory of knowledge (ie relational thinking and reflective practice) that is both diverse and hybrid as well as creative and critical (see Stewart & Shaw 1994). Indeed, as Gibbons et al (1994) argue, modes of knowledge formation which have emphasised disciplinary unities and transference downstream from academe to practice are increasingly becoming superceded by modes which emphasise transdisciplinarity and exchange in the context of application. In these respects, the reorientations that we have been arguing for in Organisation Studies and Computing Science would seem doubly relevant.

Finally, we also recognise that our study is one of many which considers that contemporary organised life needs to be addressed as a process of becoming that is uncertain, equivocal and open-ended. In such circumstances, contemporary transition needs to be understood as neither benign nor authorially controllable, but imbued with both unwritten opportunity and the limits of contestation. Hence, we can but go on with resourceful fortitude to participate in everyday struggles for 'manageable' forms of ordering, a critical form of involvement in complexity that is neither nostalgic or nihilistic. Ultimately, we would argue that such an (un-modern) engagement with contemporary organised life is more complex, more problematic but more appropriate

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[2]Here it is important to acknowledge the significant influence of recent work informed by actor-network theory, see Cooper 1995, Law 1997.

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