# Applications of numerical modelling in hydroinformatics

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## ABSTRACT

After a brief review of the mutation from modern to postmodern conditions of society, that is, from societies of knowers to societies of consumers of knowledge, the position of the knowledge provider in hydroinformatics is introduced. The provider's changing role in a society with an ever-increasing emphasis on communication is introduced. The sociotechnical forces that have driven numerical modelling, first from second to third generation, then to the fourth generation, and now into a fifth generation, are explicated. These forces are exemplified by an increasingly active stakeholder participation in projects, joint policy formulation and on-line management. The applications to the increasingly problematic developments in the so-called 'Third World' are then considered.

The overall consequences for the future of numerical modelling practice are then explored. The role of open-source software developments interacting with proprietorial software, together with the development and introduction of service-oriented architectures are explained. The concept of the knowledge supply chain is then advanced to introduce the concept of the extended halo of the global knowledge provider. This paper concludes with an analysis of appropriate and less appropriate business models.

**Key words** | hydroinformatics, packaged and web-based modelling

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## ON ORIGINS

Applications of numerical modelling, like applications of almost everything else nowadays, are characterised by a change in the way that knowledge is produced and employed within society. This change is commonly described in terms of a transformation or mutation *from a modern to a post-modern condition* of society that is indeed characterised and even defined by a change in the way that knowledge is produced and employed. Pioneers in post-modernism, such as Jean Baudrillard (as in *Le Système des Objets* (1968) and *La société de consommation* (1970), followed by works such as *Pour une critique de l'économie du signe* (1972) and *Simulacres et simulation* (1981)) and Jean-François Lyotard (as in *La condition postmoderne* (1979) and many subsequent elaborations, such as those collected together as *Le Postmoderne expliqué aux enfants* (1988)) outlined the manner in which this process was proceeding initially in terms of what we should now call *the knowledge content of artefacts*. Thus, over and above the actual manpower employed in manufacturing a motor car or a kettle or a dress, or indeed almost everything else, there is encapsulated the knowledge of how these artefacts should be researched, designed, tooled, supply-chained, manufactured, distributed, advertised, sold, maintained, discarded, scrapped and indeed processed at all levels, from their conception, through their consumption, to their disposal, that is, through their entire 'life cycle' (Abbott 1993, 1996). Already in the 1970s, however, it had become increasingly clear that this process would not, and indeed could not, stop at the knowledge content of artefacts, but *must continue to encompass knowledge itself*. These pioneers then discerned already at that time a transformation or mutation *from a society of knowers*

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*to a society of consumers of knowledge*. Within this new, postmodern, condition of society we then come to distinguish between *knowledge providers* and *knowledge consumers*. We may, and nowadays commonly do, see this social transformation or mutation as the social impulse that led to the birth of the Internet and, even more decisively, to the semantic web that came to be superimposed upon the net. A world in which knowledge itself becomes a 'consumer good' is then, however, a world in which communication must take on a new role, such as must promote 'the destruction of distance', as this is now realised most aptly by an ever more versatile and ubiquitous mobile telephone network with an apparently never-ending number of new functionalities. *Whoever speaks of society speaks of communication* and this has never been as obvious as it is today. The water sector can no more escape from the exigencies of this kind of activity and the sociotechnologies that accompany it than can any other sector of industry (Abbott 1991).

## SOME BASIC NOTIONS AND EXAMPLES

In order that an organisation may live by being a knowledge provider, it must have *a higher level of knowledge* than its business environment of knowledge consumers. The notion of 'a higher level of knowledge' implies that the knowledge provided must be relevant to the consumer and that it should, in most cases, be *actionable*, that is, it should enable the consumer to take actions that he or she would not otherwise be able to take. Since such knowledge must then be relevant to the consumer, there must be a *relevance relation* between the provider and the consumer. If the relevance relation is a close one, the 'distance' between the knowledge of the provider and that of the consumer is small, while conversely, if the relevance is a distant one, this 'distance' between the provider and the consumer will be correspondingly greater. The difference between the knowledge level of the provider and the knowledge level of the consumer divided by this 'distance' between them, as expressed in terms of the relevance relation between them, is called the *knowledge gradient*. In general then, the greater this knowledge gradient, the more that knowledge will tend to pass from the provider to the consumer. To the same extent that this knowledge is actionable, so the greater is the *value of the flow of knowledge* from the provider to the consumer.

This flow, however, can then be augmented by increasing the number of consumers and the rate at which they consume knowledge. Correspondingly, the value attributing to the provider increases with increasing numbers of consumers and with the frequency with which they consume the proffered knowledge. Since these numbers increase the more the same knowledge is used and reused, time and time again, so the value increases further with the *rate of circulation of knowledge* through the provider.

Correspondingly again, the value of its knowledge to a knowledge-providing organisation is proportional to the sum over all consumers of the products of its knowledge gradients with its rates of circulation of knowledge. The coefficients of proportionality that relate this to the money income are measures of the social values of knowledge provided to the consumers.

Thus, if the knowledge gradient is small, the knowledge must circulate with great rapidity in order for the organisation to be commercially viable, as in the case of producing and selling hamburgers, and if the knowledge gradient is large the rate of circulation may be substantially lower even while the organisation still remains viable, as in the case of software-package producers and most consulting engineering companies. The coefficient of proportionality may then, in this case, be introduced to provide a notional cash flow generated by the knowledge concerned: see Abbott *et al.* (2005).

A corollary to this is that in any change of paradigm, in which new knowledges tend to displace existing knowledges so that the rate of circulation of these knowledges that are being displaced can be expected to decrease, the new paradigm will be vigorously opposed by many persons who feel threatened by the consequent changes in economic and employment opportunities.

## EXAMPLES IN NUMERICAL MODELLING

Let us exemplify this by referring to the third, fourth and now fifth generations of numerical modelling in hydraulics, hydrology and water resources generally. We may recall that the first generation was concerned with numerical solutions to algebraic equations, the second with project-customised modelling, the third with the introduction of modelling systems for constructing individual models, the fourth with the packaging of these modelling systems into products and the fifth, currently ongoing, proceeding within the 'Software-as-a-Service' (SaaS) paradigm. In the case of the third generation, the modelling-knowledge gradient was almost invariant over all the users, in the fourth this gradient varied substantially so that active support functions had to be introduced (e.g. local agents in many countries, regional short courses and conferences, computer-aided telephonic advice serving, etc.) and in the fifth generation the modelling-knowledge gradients could vary even more again, even as a whole new strata of web-based supporting functions and activities, that will be reintroduced later here, had to be incorporated. On the side of knowledge circulating through the providing organisations, this knowledge circulation increased from only a few projects a year in second-generation modelling to a few hundreds of projects a year in the third generation, then to many tens of thousands a year in the fourth generation and it is expected that this will pass to many millions of applications a year in the fifth-generation paradigm, as outlined in earlier contributions and publications (e.g. Abbott & Jonoski 2001; Abbott *et al.* 2006*a*,*b*; Abbott 2007) and as will be introduced very cursorily here again.

At the same time, for reasons that will again be exemplified in the next section, the nature of the knowledge that is brought into play changes rapidly also when passing from applications of third-generation to applications of fourth-generation modelling, and then even more rapidly again in applications of fifth-generation modelling. Alongside and inseparable from this, the complexity of the *knowledge supply chains* increases as one passes from one generation to the other, as will also be explained later here.

In the transformation from third- to-fourth generation modelling, that is from *institutionally centralised modelling-as-a-service* to the provision of 'packaged' software to realise a paradigm of *modelling-services-as-products*, the level of computational–hydraulic knowledge required of the user was reduced dramatically, but this was often more than compensated for in practice by the integration that was thereby realised with the other scientific and domain knowledges that the clients for the 'packages' brought into play during the modelling applications. The knowledges that come together within such a context are themselves bound together by what are called *conjunctive knowledges* and these are indispensable adjuncts to the transformation that is our main concern here. In the fifth generation of modelling that is now moving down upon us this tendency increases greatly again, as will now be exemplified.

## ACTIVE STAKEHOLDER PARTICIPATION

As introduced in an earlier contribution (Abbott 2007) the general purpose of active stakeholder participation is to induce a change in the built environment that aligns with a positive change in the social environment. When this positive social change is not realised, the process of attempting to transform the built environment suffers accordingly.

The purpose of stakeholder participation within the social environment itself is then to transform this environment from a *reactive* one (in which each stakeholder *reacts individually* during the course of a *purely technical transformation* solely on the basis of the most immediate social consequences for that individual stakeholder) into an *interactive* one (in which each stakeholder *interacts with the other stakeholders* within a community, where by the different stakeholders come to cooperate in the forming and shaping of the transformation as a whole, making of it an *essentially sociotechnical transformation*).

Then, in the very succinct words of one of the reviewers of this paper:

> 'Stakeholders require the ability to manipulate calibrated/validated models for alternative analysis, knowledge and insight generation, and decision making just as much as subject-matter experts do. However, SMEs are still needed to fully calibrate and validate models, to maintain these models as living models that are updated as new data is obtained, and to document said calibration/validation in a manner that is understandable by stakeholders.'

Continuing to recall the earlier work (Abbott 2007) it is then necessary to emphasise that any project involving stakeholder participation comes to exist in two 'worlds'. The first of these is the external, physical world, or *outer world*, in which the project comes to presence as a tangible object, and the second is the internal, mental world, or *inner world*, in which the project is experienced, evaluated and subsequently influenced by its various stakeholders. Such a project involves an interaction or interplay between these two worlds and its success or otherwise depends upon the outcome of this interaction or interplay.

The manner in which active stakeholder participation changes the way in which the individual stakeholders think and feel about the world in which they live and function is to be taken up in some detail in another paper again and so will not be further introduced here. All that needs to be emphasised is that, through stakeholder participation and involvement, each of the individual stakeholders attains not only to a broader, but also to a higher, level of collective understanding, and *this leads not only to a higher state of collective consciousness but also to a higher state of* collective conscientiousness that can decide issues that are, in the abstract, unresolvable.

Thus, to reiterate, every project involving active stakeholder participation has to comprehend these two very different aspects that often appear as two different worlds. On the one side it has to do with *creating in the outer world* of physical forms and activities, while on the other side it has to do with the *creating in the inner world* of human minds as these come together through communication, subject to specific social arrangements. Being creative processes, both are technologies, the one being a technology of the outer world and the other of the inner world (Heidegger 1963). The first of these is constantly advancing of course, but it is the second that is advancing so much more rapidly today due to the catalytic effects of advances in the Internet and the World-Wide Web and, much more again, by the rapidly ongoing advances in applications software and supporting services that are enabled by these facilities. Previously, what happened in the outer world was what was obvious because it was immediately visible and tangible, while what happened in the inner world was mostly hidden and usually unheard and unfelt in a wider circle. Now this situation changes as the inner world broadcasts its observations, inspirations and aspirations through the developments made possible by advances in the computation and communication technologies and the proper understanding of their appropriate applications. The most immediate consequence is that the media loses its quasi-monopoly in the technologies of persuasion, as these are increasingly appropriated by web sites, 'blogs' and other instruments of the environmental and other, less regular, bodies.

Although the developments described here are of capital importance in the so-called 'third world', we shall not repeat here the lessons of the earlier publication (Abbott 2007) that explained the nature of the social changes that these developments have the capacity to catalyse, even why explaining why they are, for the most part, not being taken up into development practice. It is only practical in this place to introduce what was omitted from the earlier work, that behind the failures of so many development projects in the 'third world' one observes that the relations between those promoting such projects and those who are realising and operating them are afflicted by technocratic attitudes that Heidegger characterised in terms of *deficient modes of solicitude* (Heidegger 1927, pp. 122–123 (1958, pp. 158–159)):

> [Even] with regard to its positive modes, solicitude has two extreme possibilities. It can, as it were, take away 'care' from the Other and put itself in his position in concern: it can *leap in* for him. This kind of solicitude takes over for the Other that with which he is to concern himself. The Other is thus thrown out of his own position: he steps back so that afterwards, when the matter has been attended to, he can either take it over as something finished and at his disposal, or disburden himself of it completely. In such solicitude the Other can become one who is dominated and dependent, even if this domination is a tacit one and remains hidden from him…
>
> In contrast to this, there is also the kind of solicitude which does not so much leap in for the Other as *leap ahead* of him, …not in order to take away his 'care' but rather to give it back again to him authentically as such for the first time. This kind of solicitude pertains

> essentially to authentic care…; it helps the Other to become transparent to himself *in* his care and to be *free for* it.

This manner in which even an apparently positive mode may, in fact, be deficient is often experienced where an aid recipient is only 'receiving instructions', basically only being 'trained', rather than being challenged-out to develop his or her inherent capabilities and to exercise these independently.

From a sociotechnical point of view, the poor and oppressed in the 'third world' have been, for the most part, disenfranchised within projects, and even when they have been, to some extent, enabled, because they lack *power*, even as the success of the projects depends fundamentally upon the *knowledge* of just these persons. This disenfranchisement occurs in turn because the knowledge that this great majority possess is, for the most part, not accepted as such by those who are nominally responsible for the projects concerned, who see themselves and the more privileged minorities with which they cooperate as the repositories of 'the only true knowledge', which they like to associate with 'modern scientific knowledge'. Reverting to the terminology of a Husserlian phenomenology, the indigenous knowledges are, for a large part, *pre-predicative, pre-linguistic and thence pre-scientific*. They accordingly often appear as *mythical*, which is to say that these knowledges presuppose the existence of sign functions $m$ that map a text ($m$) into a context ($m$) in such a way that, whenever those who become susceptible to the myth are confronted with the text, the context becomes reified in their minds:

$$m : \text{text}(m) \rightarrow \text{context}(m)$$

where of course we are using the word 'text' to apply to any knowledge-bearing artefact, or indeed to any knowledge-bearing phenomenon (Dilthey 1976). Thus the myth itself is not the text alone, nor is it the context alone, but it is both of these together with the function of the mind that effects this mapping from the first to the second. We then further recall, with Lévi-Strauss (1958, p. 231, with emphasis added) that:

> A myth is always related to past events, 'before the Creation', 'during the earliest times', or 'once upon a time'. But the intrinsic value that is attributable to a myth comes from this: that the events that it recalls, appearing to take place at some moment in time, also form *a permanent structure*. It is this that relates itself simultaneously to the past, the present and the future.

These features were already taken some steps further in Abbott (2007) and are taken much further again in Abbott & Vojinovic (2009*a*,*b*) in setting out the principles of this kind of environment in much broader social terms.

## THE FUTURE OF NUMERICAL MODELLING PRACTICE

As should now already be clear, our current difficulties are no longer so much associated with numerical–computational software as such, but much more with the way in which this is to be used: how it is to integrate into its social context and how it in its turn reacts to this context. Casting around for similar situations, and even for paradigm cases, a particular interest accrues to the reason for IBM's recent and quite dramatic turnaround, which is usually traced to its embracing of so-called *middleware*, understood as software that acts as a layer between the deeper-level workings of the operating systems and the applications, and then in such a way as to promote a wide range of new applications. In the case of fifth-generation modelling practice, middleware is that which interfaces between the generic and domain knowledge encapsulated in, and produced by, the numerics of the application and the resulting knowledge delivered to the consumer. Whereas in third- and fourth-generation modelling this task could be managed simply by introducing more sophisticated user interfaces, in fifth-generation modelling this is no longer possible as and by itself because no user interface, in the present understanding of this term, could accommodate itself to the knowledge levels and the diversity of knowledges, not to speak of the conjunctive knowledges, of the many prospective consumers. Already in current multi-stakeholder participation, many different kinds of stakeholders are engaged and each has their own need for knowledge, as this is made available in stakeholder-customised form and backed by understandings that also have to be inculcated and supported. When moving into advice-serving systems that are customised over some tens or even hundreds of thousands of consumers, such as a great variety of kinds of farmers and aquaculturists and water-born-disease-oriented health care providers, the range of presentation and reaction-capturing scenarios is virtually unlimited.

This 'explosion' in the range of applications that will then have to be served by the products of future knowledge providers necessitates a complete rethinking of these products in terms of their social applications and reaction of the social applications upon the knowledge provider, and with this the elaboration of new and various business models. The risk is always present when a new paradigm emerges that the established provider will have become so locked into the business model of the already-established paradigm that it will be unable to adapt, with serious consequences for its competitiveness. The experience of IBM as it has extended its own middleware reach seems very apposite to the position of knowledge providers in the international water sector, and especially to its global knowledge providers (Richard Waters, *FT*, 28 February, 2007):

> Behind this growth lies a strategy that sounds starkly different from rivals Microsoft, Oracle and SAP. While these companies have been racing to create 'stacks' of corporate software, extending all the way up to applications used by individual workers, IBM has concentrated on creating a 'horizontal' layer of middleware that lies in the guts of IT systems, where most workers will never encounter it.
> That strategy relies on the belief that legacy corporate IT systems are measured in trillions of dollars…, requiring extensive work as companies try to adapt them to new business purposes.

From this, however, follows something more significant again, and one that has strongly motivated the *Water Knowledge Initiative*, namely:

> [Mr Ian Finley, research director at AMR, a technology research firm] says that IBM's middleware strategy has positioned it well for one of the biggest shifts currently underway in software: the rise of so-called 'service-orientated architectures', or broader and more flexible platforms upon which companies can build more adaptable technology capable of changing with their business needs.
> …Some other broader software trends, however, may pose a bigger long-term challenge.
> One is the rise of open-source software, a movement that IBM has itself championed by supporting the use of the Linux operating system.
> …"The open source model is certainly viable" argues Steve Mills [executive in charge of the middleware division of IBM]. IBM has itself started to offer open source versions of some of its middleware, starting with application server software, for the low end of the technology market. But Mr Mills admits that "to avoid seeing the more profitable part of its business commoditised, we have to keep moving up" to higher-value areas of software.
> The second potential challenge comes from the emergence of "software as a service" – the business of providing applications online as a service to companies… Companies attracted to these services will no longer need to buy the hardware systems and IT integration sold by other parts of IBM, says Mr Finley, putting pressure on IBM to step up its efforts to become a full service provider.

In the water sector, as in many other sectors besides, the major players in the field of knowledge provision with their emphasis on numerical modelling have, just like Microsoft, Oracle and SAP, "been racing to create 'stacks' of corporate software, extending all the way up to applications used by individual workers". Nearly all of this is currently closed-source. If we now compare the preceding observations of this section with the current situation, we see that there is a mis-match that must become ever larger as and when the water sector comes to transfer the knowledges of its participants through encapsulations in code and thence over the semantic web. This is because the knowledges concerned are so many and so varied and even so difficult to identify in advance that the major providers cannot possible hope to encompass them, but must rely increasingly upon other participants on the supply side to contribute much more easily and effectively in the processes of knowledge provision. And this can only be realised by providing links to the productions of the major players by providing open-source software with which they can most conveniently interface. The positioning of such open interfaces within open-source software is a strategic decision for any and every major player in this sector. Thus, for example, the decision to go ahead with the construction in open-source code of vehicles for the instantiation, running and delivery of results over the web, as the first stage in what has become known as the *Water Knowledge Initiative*, was intended to initiate just this 'opening-up' process.

(The *Water Knowledge Initiative* was founded by the present authors as a partly closed-source and partly open-source movement with the aims of:

(1) Establishing a new way of working between electronically encapsulated knowledge and human knowledge and understanding in the water sector of industry;
(2) Establishing a new way of communicating between stakeholders;
(3) Establishing a new way of working between industrial organisations and educational and research organisations in the water sector generally;
(4) Establishing new business models within new industrial cultures and establishing these in the water sector.

The *Water Knowledge Initiative* was intended to make a much fuller use of the World-Wide Web than ever before in the field of water: see Abbott & Jonoski (2001) and Abbott *et al.* (2006*a*,*b*). It is now proceeding correspondingly).

We may observe in passing that we are only concerned here with *creative businesses*, defined as in Abbott (2004):

> A creative business is one in which the transformation from the objects of the business into their social values is maintained in a right balance with the transformation of these same objects into their intrinsic values.

Put into more practical but less precise terms, a creative business is one in which one does not build the business in order to make money but one makes money in order to build the business. The difference then resides in the most vital issue of all, which is that of *intention*.

It is often said that the expression 'open source' can mean almost anything, and certainly looking at the more than 100,000 currently operating open-source movements might suggest this interpretation, but the reality of the present situation insists that *the expression 'open source' can mean just what you want it to mean within your particular application* (Harvey & Han 2002, 2003; Abbott 2003).

To be very blunt about this within our present context, the notion that a few organisations should continue 'racing to create vertically integrated "stacks" of corporate software, extending all the way up to applications used by individual workers' is a snare and a delusion in our case as much as in any other: it is Hubris on the largest scale within our field of endeavour. The very notion that one can close the door upon the creativity of the thousands of others in the sector by building walls in the name of 'defending intellectual property' is untenable within the world that is now opening up in this sector, as indeed it is every bit as untenable in most other industrial sectors besides. Open-source applications are essential to release the creativity of others who can then become de facto partners in a larger enterprise: it is these that provide the halo that promotes and protects the more open enterprise. No organisation, no matter how well founded otherwise, can have a monopoly upon creativity.

We can add to this from the side of the client, that is, from the final point of sale, that to continue with marketing 'stacks' of corporate, closed-source software is to push the trust of the client beyond what is normatively reasonable, with subsequent reactions from that side too. Clearly, as the client organisation acquires more applications, so it may well graduate to packaged systems for reasons of greater economy, but it can then take the halo established by the new paradigm with it back into the fourth-generation environment, as a kind of retrofitting operation. But in order to follow this process, some further aspects must now be introduced.

## KNOWLEDGE SUPPLY CHAINS AND THEIR ANALYSES

Just as physical components are brought together and 'assembled' to form cakes or motor cars, so we can abstract the knowledge contents that make, in this case, the knowledge contents of cakes different from the knowledge contents of motor cars. Here we can already see that the assembly process necessitates the presence of that something else again that we call understanding, whether present already in the assembler or brought to presence, or learnt, from another source, such as a cookbook or an assembly instruction manual. And thence we can proceed further again to consider knowledge itself, abstracted from its tangible expression other than in strings of binary digits passing through digital processors. This same process of abstraction thence leads us to proceed from the physical/ tangible world of artefacts to that which forms all artefacts, which is knowledge itself, subject to the actions of the understanding. Correspondingly, just as there is a vast area of knowledge concerning supply chains appertaining to physical objects, so there must be a knowledge of supply chains pertaining to this 'knowledge in itself'. The study and employment of the resulting *knowledge supply chains* is accordingly an extension, an extrapolation and a reformulation of existing supply chain analysis as this is so widely employed in the world of physical/tangible objects.

The matter of tracing the flows of knowledge from person to person, from codes to codes and from environment to environment and so on was unnecessary in the case of third-generation modelling and neither was it of much interest in fourth-generation modelling, outside of introducing various modes of 'customer support'. This was because the knowledge supply chains in the corresponding environments were so simple as to need no serious analysis. In the case of fifth-generation modelling, on the other hand, the knowledge supply chains quickly develop many links, becoming multiply connected, interacting the one with the other, whether through conjunctive knowledges or by sharing data or by sharing users, etc., introducing recursive processes on knowledges, etc., etc.. Correspondingly, the analysis of knowledge supply chains becomes significant even as the analysis itself becomes more complicated and correspondingly more difficult. This analysis and the control structures that it produces are established in the case of knowledge of financial flows, as exemplified by the systems of *SAP* and *Baan*, but these deal for the most part with locally time-invariant situations, whereas here we are dealing with relations that are changing in time, and sometimes changing rapidly in time. The situations in which specific elements of knowledges are called, the order in which they are called, the conjunctive knowledges that are set into play and the way in which these in turn interact between themselves through the application of understanding now become issues that have to be addressed. There are, of course, many tools available that might in principle be adapted to facilitating the construction of knowledge supply chain management applications, but the searches so far made have not provided promising solutions for cases of the present kind. Of course, a lot has been written on the subject of 'knowledge mapping', but this appears to be far too simplistic in its assumptions for the kinds of applications with which we are concerned here. In the present connection, *it is the relevance relations that provide the links in the supply chains*, and, following Foucault (1980), *one must always trace these backwards, starting from the point of knowledge consumption*.

What has to be achieved in this place is to bring together and to integrate the knowledges required by a particular person in a particular place in a particular situation at a particular time and then for as long as this integration is necessary–for we are here dealing for much the greater part with a *consumer of knowledge*, and much less with a *knower*.

Even the market identification is often obscure in this case: Is it a market for software (like UNIX, OS400, Oracle, etc.)? Or is it a business of selling licences (like *SAP*)? Or is it a business of selling computer services (like Accenture, Ernst and Young, KPMG and PwC–Price Waterhouse Coopers)? Or, which is much more likely, is it none of these, but something quite else again (like the *Water Knowledge Initiative*)?

The remote building, updating and using of water-related models is the foundation upon which the potentially unlimited panoply of application software, as supported by human understanding, has to be established. This opens up new fields of endeavour of which only a brief introductory sketch can be provided here. The study of this field is a new one in the discipline of hydroinformatics, but a study that is now beginning to become urgent.

This discipline cannot, of course, neglect 'the human agent', which must of course enter as a subject in his or her own right, and often as the surrogate of many other creatures than mankind itself. The community of persons brought together around a particular artefact of the kind that is being adumbrated here is a community of caring-about-something, and thus has its own kind of solicitude-towards-those-others-who-care. Taken together, these constitute, once again, *the extended halo* of any and every such artefact. The study of knowledge supply chains is then again an *essentially sociotechnical* study. This is then to say, and for the *n*th time, that if treated only technocratically it will do more harm than good and fail entirely to meet the real demands of a rapidly changing world.

## THE HALO OF THE KNOWLEDGE PROVIDER

The post-modern knowledge provider is one who has already encapsulated the most strategic elements of its knowledges in code and has made these knowledges available over the semantic web while at the same time supporting these 'virtual knowledges' with human understanding, as also disseminated through the web. The successful post-modern knowledge provider, on the other hand, is one who has created *the most numerous, the richest in knowledge and understanding and the most varied of halo participants*–those who understand the most about the provider's products and their applications and can support these not only with their own advice/expertise/etc., *but also with their own encapsulated knowledge, that is, their own software*. Thus, speaking grosso modo, whereas the one movement in this case is from electronically encapsulated knowledge to human knowledge, the second movement is from human knowledge back to encapsulated knowledge. The purpose of opening some part of the software engendered through the first movement, which is on the side of the knowledge provider, making it open-source, is to initiate and subsequently catalyse the second movement, thus creating a much more extensive, knowledge-enriched and supportive halo around the knowledge provider itself. The code that is activated in the halo in this way may itself be open-source or closed-source, depending on the intentions, restrictions, operations, etc., of the individual agents who are active in this way within the halo. Obviously this halo is, at most, anarchosyndicalist in its composition, so that such structure as develops is essentially emergent from within the environment of the knowledge provider and the market for the services provided by the complex that forms itself in this way (Abbott 2003). We may call the complex that so evolves *the extended knowledge provider*.

It is then clear that every knowledge provider with any such 'extended ambitions' needs to introduce parts of its code, which we shall call *sites*, that are open source and will *attract and bind* potential halo persons and organisations. The analogy and associated metaphors that are introduced here can then be taken from elementary quantum chemistry and molecular biology, where patterns of free hydrogen ions on a living organism are steriospecific with complementary patterns on the outer surfaces of molecules that need to be bonded for this organism to grow and prosper. Consequently, in the random, chaotic movements of molecules, the free hydrogen ions on the mega-molecule that is the living cell come to attract and bind with those of the so-far free-ranging molecules, bringing these into the life systems and temporal cycles of the living cell. Thus each and every halo forms itself through analogous processes of steriospecific recognition between the relevance relations situated at the links between its knowledge supply chains.

We can see in these operations something that may at first sight appear as analogous in some respects with what has already occurred within the existing knowledge providers themselves, who have introduce 'seamless interfaces' between, for example, their fluid-dynamic computational codes and commercial GIS systems. These interfaces are most commonly proprietorial, and thus in closed-source configuration. Operations of this kind are, however, quite different in principle to what we are propagating here, in that they are exostructured instead of endostructured, systematic rather than chaotic, pre-planned rather than emergent and predictable rather than unpredictable.

If we may be permitted to switch metaphors once yet again, we may now think of our knowledge supply chains as carrying cables, but now cables that, although embedded in the existing (usually legacy) software, are open at their instantiation, operation and delivery ends to the outside world and can be connected to other software/code, subject to the recognition of their corresponding functions. In IBM-speak, such interfaces are called *service-orientated platforms*. These can then be configured so as to provide bonding sites for outside developers, entrepreneurs and others in the water sector of industry generally. Obviously, just as in the molecular-biology analogy, the persons and organisations that are so attracted and come to bond may, and in many cases will, provide further such sites so as to enrich their own operations again. They may, of course, use these facilities to bond with their own legacy software and the IBM paradigm case suggest that such applications may be of great significance in our own field too, opening up wider perspectives again. The possibilities for flexibility in pricing policies are obviously unlimited within this model. This development has the added consequence that, whereas in fourth-generation modelling one unique user interface might suffice, in fifth-generation modelling some tens of different kinds of user interfaces may be required for stakeholder participation, while in applications of mass-customised advice-serving systems some thousands of mass-customised user interfaces will be necessary. This development alone necessitates a rethinking of the functionalities and even the architectures of the software involved.

## APPROPRIATE AND LESS-APPROPRIATE BUSINESS MODELS

The above observations make it possible to spread some light on the question concerning the business models that may be the most appropriate within some specific sociotechnical contexts. It must then be accepted, however, that this light will be of little value as and by itself in many and possibly most places, where decisions are not taken on the bases of analyses of the above kind, but on quite other grounds, such as the availability of specific kinds and conditions of financing, the persistence of habits of thinking that, although they were relevant within earlier paradigms, are becoming much less relevant within the now-emerging social and sociotechnical conditions, the associated personal interests in protecting narrow fields of expertise that do not appear to fit into the new paradigm, corresponding fears of changes that will upset the power/knowledge relations that provide inner-institutional advantages, and many other similar factors. It is very rare indeed that a change of paradigm such as this can be engineered easily within existing institutional structures and, correspondingly, great care and attention are required to realise institutional changes of the kind that are necessary here. Thus it is not enough to identify the one or the other preferred business model without developing a plan of how this model can be introduced within a given institutional context.

These observations lead to serious doubts concerning the interests of the existing main players in the modelling and related areas of the water sector in realising a change of paradigm of the kind proposed here. Their current businesses are generally sustainable and, with government support and other non-commercial funding in many cases, have little or no incentive to pursue a new paradigm of the present kind. On the other hand, and as has been experienced in the *Water Knowledge Initiative*, some persons in less subsidised environments are aware of the potential and even the urgency of the new paradigm, given the fragility, and even in some cases the unsustainability, of business operations as these are currently conducted, and especially within the current high-risk economic–financial environment.

As has been reiterated on several occasions in previous publications, the changing of a paradigm cannot normally be achieved by exhortations, no matter how well orchestrated these may be, but can be much better engineered by introducing tools as items of concern–and then employing these in order to create environments of solicitude within the group of persons employing the tools. The success of this initiating group then provides the incentive to others in the organisation to emulate its success by imitating the successful paradigm. The question concerning the introduction of the paradigm as a whole thus devolves upon the formation of this group and its leadership.

So far, during the development of applications of numerical modelling, this process was able to proceed within the established organisations through exceptional leadership, backed by a high level of domain competence. The question then devolves again upon the presence of such leadership qualities within the existing organisations in this field. This identification then leads to the search for persons within the existing organisations who have the vision and leadership qualities to promote the paradigm as far as is possible within their institutional constraints. This in turn points to the necessity to provide support to such persons, such as by relieving them of financial commitments that others in the organisation might consider onerous, and therefore oppose.

This suggests a business strategy, as more than a business plan, of setting up a company that interfaces between the knowledge provider and the entire software-as-a-service environment, including the halo and the extended halo again. As mentioned earlier, clients may be expected to return to packaged software if the costs of using the new paradigm becomes too onerous, and they can then take the whole halo and extended halo with them, so as to outsource, and even offshore, their corporate support functions. In the same vein, a package provider may choose to franchise out its dealings with the halo and extended halo to the interfacing company. It follows quite generally from this that all proprietorial software should be placed on the server side of the business so that no initiating costs are imposed upon the clients.

This, and some other tentative application and business models, have influenced the approach taken in the *Water Knowledge Initiative* ab initio. It has, for example, in some parts precluded the use of the most popular tools for communicating through firewalls between systems working on the same data, of which the most widely known are probably the various Citrix solutions and BeamYourScreen. Further, at a deeper level, as explained in an unpublished paper presented by Tumwesigye Emmanuel at the Yangtze Forum in April 2007:

> Current thin server technologies for remote software applications employ these protocols: Citrix ICA Protocol, Remote Desktop Protocol (RDP), and NX Technology and Linux Terminal Server. What is common among all these protocols is that they provide a remote software GUI to a client terminal, of course with varying degrees of success. The server technologies download screen presentations from the terminal server and upload mouse movements and keystrokes from the client computers. This approach introduces to the client the normatively *vertically-stacked* software GUI that the client has to contend with. The implementation approach in this project is that of function-based processing and it is intended to achieve some of the following objectives:

1. The server technology should be easily customisable and extendable by clients, which is not possible under the above protocols.
2. Combine the benefits of cooperative and distributed processing, where modular units reside on different platforms but may easily be orchestrated by message passing. This calls for reusable, modular units that are *horizontally-stacked* and called only when required.
3. Provide less complex interfaces to clients especially to serve inexperienced users and the different stakeholders. Single interfaces manage the complexities of heterogeneous environments.
4. Provide location independence for client applications.

The underlying communication facilities implement both message based and RPC calls to transfer dialog and data.

These early observations have been greatly extended in a thesis of Emmanuel Tumwesigye (2009), some of the results of which will be published subsequently. This work has demonstrated the practicability and, with this, the economic viability of the fifth generation of numerical modelling in hydroinformatics practice.

Although thin client applications have been avoided initially, these will be introduced subsequently, raising quite other business problems again, which must be correctly solved. The general problems associated with shared ownership of tools, reliance on external suppliers (reinforced by some very painful memories!), financial constraints and overheads, autonomy over and control of the server-side code with associated code-integrity/-security aspects and other firewall-associated constraints showed that customised access, working and delivery vehicles would be necessary if it was going to be possible to engage the existing knowledge providers in this field in a constructive way. The approach that is taken here also simplifies the problems of *distance control* and especially those of financial control of the necessarily distant encapsulated-knowledge-serving and human-understanding-servicing operations (see, for the sociotechnical background in this case, Law (1986, 1991)).

## CONCLUSIONS

A new paradigm in the use of numerical models in hydroinformatics has been formulated. Although this new paradigm is directed initially only to extending the range of existing modelling applications to a wider range of end-users, who then become transient users, it is directed in the longer term to much larger areas of application within society as a whole. It is then, in the first place, directed towards supporting active stakeholder participation in water-related projects, where entirely new functionalities are necessary. It can be extended further to supporting mass-customised advice-serving systems for agriculture, aquaculture and water-born disease prevention and associated health care provision. It is expected that the fifth generation will extend the area of business by two orders of magnitude in numbers of end users and so by one order of magnitude in the business activities of the knowledge providers.

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