# Creative conflict in interdisciplinary collaboration: interpretation, scale and emergence.

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We are part of an interdisciplinary collaboration that has been investigating new theories about stem cells. Medical research into stem cells has increased significantly in recent years and there are now major efforts worldwide to understand stem cells, and harness their potential capacity to proliferate and produce any specific type of cell that might be required in order for the adult human body to survive. There is no doubt that a greater understanding of the behaviour of the entire set of stem cells in the adult body may give us insights into how we combat diseases such as cancer and Parkinson's. Radical new theories of stem cells have seriously challenged commonly held views within the medical community, and our team was charged with a simple aim, namely to discuss and investigate them. Our project had no set objectives, and as such the research was process-based (a radical departure for some of the scientists on the team). It was an exploratory activity that started by looking at two specific areas of scientific and artistic innovation, and as such it is as much about the nature of discovery and how philosophies change as it is about specific areas of research. To progress the project we used the skills and methods from our various disciplines to collectively undertake a sustained enquiry into this field. Throughout our many encounters, that took different forms from phone calls, to emails, to face to face meetings, several key issues arose continually over which there was much debate and conflict. This conflict challenged many of the pre-conceptions that were an implicit part of our respective disciplines and in this paper we identify some of these, and consider them in some detail.

We report the experience of working on an interdisciplinary project (CELL) looking into innovative theories of stem cell behaviour. Stem cells have been viewed as special cells that are able to sustain their own population as well as produce the right levels of the various functional cells (heart, brain, liver and so on) necessary to maintain a healthy human body. In order to contextualise some of the insights we have gained through working together on CELL we will start by giving a brief introduction to each of the collaborators.

## 1. Introduction

Prophet is an established artist and Professor of Visual Art and New Media at University of Westminster in London, her work includes Alife artworks such as TechnoSphere (Prophet 1996) and a series of artworks that challenge ideas about landscape and nature (Prophet 2001). d'Inverno is Professor of Computer Science at University of Westminster whose research focuses on building mathematical models of new technologies in computer science and is best known for his work in multi-agent systems (d'Inverno 2004). Theise is a liver pathologist based at Beth Israel Medical Center in New York, he was among the first to show that adult bone marrow stem cells have surprising plasticity and can transform themselves into the mature cells of other organs (Theise 2002). Saunders was a pioneer in developing a computational model of curiosity using specialised neural networks, he also models creativity, focussing upon the roles of novelty and emergence in creative processes (Saunders 2004). Ride commissions and produces artworks that address artists' use of digital technology, developing new forms and systems that enable them to create innovative work. He is the Artistic Director of DA2, Digital Arts Development Agency (Ride 2004), which primarily works with seasoned collaborators, namely artists operating in hybrid practice through interdisciplinary partnerships. He co-Directs The Centre for Arts Research, Technology and Education (CARTE) University of Westminster (CARTE 2004) with Prophet.

Each of the individuals involved in CELL operates within a different experimental research environment: Theise's medical laboratory; d'Inverno's and Saunders' respective mathematical and computer science labs; and Prophet's artist's studio. These provide different and specific contexts for the work and have particular embedded methodologies that have influenced the way the research has developed. The research is situated in sometimes conflicting cultures, ranging from the hypothesis driven ethos of the medical research lab, to the reflexive practice of the art studio, and the empirically driven environment of mathematics. Mathematical empiricism demands that through CELL we will aim to find answers to how stem cells behave, and attempt to model the 'truth' of adult stem cell behaviour. Simultaneously, the extra-contextual framework of art counters that there is no truth, only subjective interpretations and constant slippage of meaning (and that the goal is to ask questions rather than find answers).

There are a number of outcomes to our collaboration

- sole and co-authored papers in peer reviewed medical journals, mathematical modelling journals, simulation journals, art journals and interdisciplinary journal
- a mathematical model of the new paradigm
- a dynamical simulation of the mathematical model
- art installations exploring the nature of scientific representation
- innovative interactive devices and systems: namely 3D illustrations of cells and their behaviour generated using Alife techniques
- detailed documentation of all the processes involved in this project

Through the process of working in this interdisciplinary team we identified a number of issues over which there was continual disagreement and discussion within the team. We found ourselves returning time and time again to some of these differences. Our negotiation of them became central to the development of the common conceptual framework that was necessary in order for us to progress the project. This conflict was creative: seldom did any individual doggedly attempt to 'recruit' another or browbeat them into agreement, instead we each asked many questions about why certain paradigms were in place and what it would 'cost' someone to contradict them. Through such discussion we each developed deeper understandings of the discourses and context that the others worked within. This caused us to question our individual assumptions about other disciplines, and indeed of our own, and in most instances to revise our worldview in some significant way. We now identify some of these areas of contention and reflect on their impact on the research project.

The first area of contention that we address here arose from discussion of the way we each interpret images. Specifically the 'truth status' different team members assigned to 2D images; the use of static images to infer behaviour of a living system and the general behaviour of adult stem cells; the importance of aesthetics in scientific publications (and the different ways artists and scientists value 'beauty'). We will conclude this section by reflecting on the way that our discussion of our differences affected both the scientist's hypotheses and the way he conceptualised stem cells in general; and the way the artist attempted to encapsulate these issues of interpretation in the artwork *Staining Space* (Prophet 2004).

*Staining Space* was produced not to illustrate the science underpinning CELL, nor to educate the public about science. Instead it was intended as an 'art object for thinking', a piece of art that through the way it combined images and objects might prompt the viewer to reflect on particular ideas. Specifically, the piece presented objects and images that were at once similar, and yet significantly different, in order to suggest the differences were important. Approaching the shed-like structure the viewer first saw a large 6 meter by 4 meter glowing image of simple graphic circles in a variety of colours. As they walked past this wall of images and entered the structure itself they saw a small 4.5 inch monitor showing moving images featuring the same simple circles. In this version, created by Rob Saunders using java, the circles apparently had a meaningful relationship to each other that was dynamic and changed over time. Comparing the two types of image was intended to prompt a re-visioning of any meaning made as the viewer saw the first large still image. This related to one of the key discussion points amongst the CELL team, namely the different meanings we make when we interpret still as opposed to moving images, and how seeing objects move (behave) in relation to other objects, and in relation to their environment can lead to deeper understanding than seeing still 'frames' or moments of such a relationship.

In modelling stem cell behaviour the CELL team emphasised the importance of environment, and its relationship to any agent (cell) within it. The environment we wanted to model was not just dynamic and changing over time (as represented in the java version), it was also three dimensional. In *Staining Space* a small 12 inch rapid prototyped model of a tree is almost hidden, but a larger projection driven by a live camera pointing at this tree model is shown as a two dimensional projected image on the wall of the shed. Many people spotted the small tree, some were surprised as it made them realise the projected image was not pre-recorded but live, and not an inverted video of a real tree but an image of an artificial model of a tree. These revelations - of the significance and of what is particular about the differences between seeing something at different scales, in more dimensions and as alive (as opposed to dead tissue) lie at the heart of both our stem cell model and the *Staining Space* artwork.

The final component of the art installation was a 1.2 meter tank of clear solution that grew crystals along three dimensional model of a tree which was made using fishing line stretched on a fine steel frame inside the tank. Although the viewer did not discern the crystals growing, most people had grown crystals at school and so the tank evoked, amongst other things, a sense of organisms growing and changing over time. This simple visual device was an attempt to remind us that our understanding of the world is one that depends on us accepting that organisms change, sometimes imperceptibly and irrevocably, so slowly we cannot perceive that change unless we revisit the object or event repeatedly over a long time.

*Staining Space* reflected on the importance of scale and the visual techniques we employ in order to make the very small, in fact the unseen, seen. In the next section we discuss scale in more detail, referring to Kantian and Burkean ideas about the sublime. We propose that a contemporary sublime is connected to the awe felt when contemplating the very small as opposed to the more traditional theory of the sublime that associates it with the awe felt when looking at the very large.

We also discuss how scale is abstracted out of our formal model and, to some degree, our simulation of a stem cell system. In our case we produced a formal model (a set of mathematical relationships and rules that makes precise statements about how the system behaves, and how its state changes over time) and a description of this model in plain English. A simulation encodes these behavioural rules into an algorithmic process that can then be run as a non-graphical computer program to investigate how the system behaves over time. There is no notion of size of a system or even of quantity of cells in these models, and scale is only reintroduced and considered when we think about visualising the simulation.

However, the relationship between different scales - the micro-level (individual cell) vs the macro-level (overall system) - plays a key role in our understanding of what we mean by emergence in complex systems, of which the stem cell system is an example. From a computational perspective emergence can be seen as the conflict in our understanding between the micro and the macro levels and we consider this in more detail in Section 4. Finally we reflect on the importance of both interdisciplinary and process-based research in Section 5 and draw some conclusions.

## 2. The nature of the interpretation of images

The CELL project began when Ride introduced Theise and the first author and The Wellcome Trust (Wellcome 2004) then funded them to work together. They started by becoming immersed in each other's working culture (the first author and Ride visiting Theise's laboratory in New York, and Theise visiting London).

Through long and regular conversations, and by learning more about the *way* they each worked, as well as *what* they did, Theise and the first author identified both the importance of images to each of their practices, and some significant differences in the way that they interpreted them. For example, for Theise coming from a background in cell biology the 'photographs' of tissue slides have a truth status, and are accepted as 'proof' of experiments and hypotheses when embedded within medical science papers. The first author was surprised that the beauty of such representations, produced as part of laboratory research (see Fig.1), appeared to be important to bio-medical scientists.

In addition, there is anecdotal evidence to suggest an apparent correlation between aesthetic quality (specifically how 'beautiful' a representation is considered to be) and the publication rate of associated scientific papers.

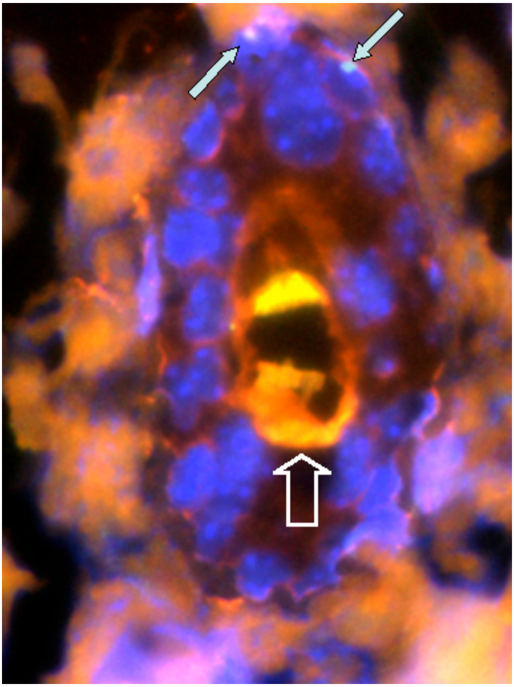

Figure 1 – Photograph of slide of skin tissue from a female mouse.

Theise and Krause (2002)

Figure 1 is an example of Theise's `beautiful' and truthful images, and represents skin tissue from a female mouse that received a bone marrow transplant from a male mouse. Blue nuclei of hair follicle lining cells surround the orange, autofluorescent hair shaft (large arrow). Two of these nuclei contain fluorescently labelled Y-chromosomes (small arrows) indicating that they derive from the donated male bone marrow, not from the female's own original cells. Thus, bone marrow stem cells are proved to have given rise to skin-type lining cells.

Figure 2 – Tree stump and wireline oak, Petworth House. Duratran 190cm x 85cm. Prophet (2003).

By contrast, in contemporary art practice photographic representations have no automatic truth-status (quite the contrary) and are assumed to be subjective. Many such images made by artists deliberately draw attention to their construction and artifice (see Fig.2). In this image the photographic representation is of the parkland at Petworth House in Sussex, England. The landscape is well known and views of it were painted by Turner. But the landscape formation is not 'natural'. It was constructed by the eighteenth century landscape designer Lancelot 'Capability' Brown, drawing on compositional techniques from contemporaneous landscape painting. Figure 2 is based on a photograph of the park as it is now, with a superimposed digital image of a simulated tree that has been generated using fractal mathematics.

Theise's research examines the plasticity of adult stem cells, which is the ability for cells that would typically develop into functional cells by following a cell lineage path, to both switch paths or even reverse along this path, and return to being stem cells. To do this he uses methods based on hypothesis and hypothesis-testing, specifically repeatable laboratory experiments and the analysis of specimens of cell tissue. The tissue is dead at the time it is analysed, and the slides are made by taking very thin slices of the dead tissue and staining it in order to highlight certain elements within the tissue (such as the nuclei that have been highlighted by being dyed blue in Fig. 1). These images can therefore be seen as representing a single frozen moment in time in the life of a complex dynamic 3D natural system, and this moment is seen from one perspective. From this perspective researchers hope to understand another aspect of stem cell behaviour, or to increase the understanding of an already known behaviour, and from any new understanding to extrapolate further hypotheses to test. The first author's experience as an artist working with time-based media and Alife suggests a different approach to assessing stem cell behaviour. Having witnessed unpredicted behaviour (only visible by watching Alife agents move and interact across time) the first author was aware that trying to discern novel activity from looking at still images and two dimensional space can be very difficult. The subtleties of dynamic relationships that occur between changing organisms, and that are situated in three-dimensional space are often rendered invisible when encapsulated in a still image. As it is not possible to look at the living complex system of adult stem cells without removing them from their environment (the body) and therefore isolating them from enzymes and other environmental actors that may impact on their behaviour. We therefore decided to develop an agent-based (ALife) engine to enable the scientist to look at *simulated stem cell behaviour as it happens* within the complex system of a wider community of cell types and enzymes.

It is a currently held belief in the medical sciences that single 2D images of cells show us fragments of a 'narrative' and that, in the case of using tissue slides of carefully selected human cells, we simply have to extrapolate from these and fill in the gaps in order to understand the 'story' of cell behaviour. To consider this in more detail, it is as if these images function like stills from a reel of film and the assumption is that we can infer a linear progression from one keyframe, or image, to the next. However, it is our belief that this understanding needs to be challenged. In particular we take the position that rather than using the analogy of cell tissue slides being like still frames from a linear and progressive cinematic narrative, these images act like nodes, or points in time and space, each one of which can be connected to more than one other node to form a non-linear narrative. Indeed it's not clear that these images can be seen as nodes at all, but rather as clues to the truth. The significance of this analogy is that when looking at a single image, the next step in the 'narrative' cannot easily be inferred as we do not know which of a number of possible connections between images (nodes) will be followed. We surmise therefore that a more complete way of understanding a natural system is as a living dynamic whole, and that to model the whole at different levels of abstraction and at different scales (rather than only look at discrete parts) will offer us a more complete narrative. We do not suggest that tissue slides and other 2D snapshots are obsolete, quite the contrary, but that seen alongside a model of the whole system they may be better, or differently interpreted.

In summary, in stem cell research, still, two-dimensional images generated from dead tissue are used to infer general properties of stem cells in the living adult human body. Our hypothesis is that these kinds of experiments are fundamentally limited and that a more holistic approach is necessary to build different models of stem cell systems. Effective ways of producing these models include mathematics, simulation and art. Modelling a system at a range of different scales and disciplines, that can be easily switched between, enables more comprehensive understanding of the system and how the whole is a function of the behaviour and interaction of the component parts.

## 3. Scale

Aesthetic debates concerning scale are central to the CELL project. The first author has been interested in the 'sublime' in contemporary culture for a number of years, in particular, fractal mathematics and an apparent cultural shift to a sublime of the very small and detailed. This develops ideas of the ‘natural’ or ‘religious’ sublime (12), based on our experience of the human body in landscapes so large and overwhelming that they prompt a sense of awe and momentary terror. The human body has historically been used as a reference from which we derive notions of scale. In the late 18th century Edmund Burke (Burke 1909) and Immanuel Kant articulated the sense of overwhelming scale felt by people contemplating large scale natural forms such as mountains or waterfalls and named this phenomenon the sublime. For the philosopher Kant (Kant 1764), the sublime could be divided into two categories, firstly the mathematical--that which is "not to be sought in the things of nature, but only in our ideas", and secondly the dynamic--that which is felt when we observe in nature mighty objects from which we are in no danger, and regard these objects as fearful without being afraid of them”.

In recent years, across disciplines ranging from physics to biology to mathematics, there has been a re-emphasis on scale, but this time the focus is on the very small. With electron microscopy, particle physics and nano science we again use our bodies as a field of reference for scale, but this time to contemplate objects of a size invisible to the naked human eye. We might describe these minute objects as prompting an equivalent sense of the *sublime of the small*. Experiencing the sublime of the small is indirect and mediated as our eyes cannot discern such scale unaided, and we can only see objects that exist at this scale by using electron and electron scanning microscopes to capture images of them. These mediated images, or representations of previously invisible objects, prompt a familiar mixture of beauty and fear – the sublime. Most common are the medicalised images from the hitherto invisible realm of the human body which are often beautiful and at the same time they frequently signify illness or disease. These images of diseased cells and contagion prompt fearful feelings as we contemplate the unfathomable wilderness of our inner landscape, one that is out of our control and untameable.

Saunders and the second author have a different interest in scale as it is also the case that emergence only arises in multi-agent/complex systems when the number of interacting autonomous agents is sufficiently large.

## 4. Role of simulation and nature of emergence (relationship between micro and macro scale)

Before we discuss scale and its relationship to emergence in particular in this section it is worth first providing some basic background on what it is to provide a formal (agent-based) model of a stem cell. When we come to build a model of a stem cell we used two basic properties. First, the current state of the cell (you can think of these as internal counters that cannot be observed directly by others), and second the range of potential behaviours that cell could do next. In our model we have essentially one model for all kinds of cell. Just to give a flavour, specific internal counters model how determined the cell is (how far down the cell lineage path the cell is), how likely it is to behave like a stem cell rather than a functional cell, how likely it is to divide and what kind of division is most likely. The second aspect is to define state changes, ie the possible transitions available which take a cell from its current state to a next state. These transitions cannot always occur but depend on the current state of a cell.

The current state of a cell at any time is then a function of its initial state and the sequence of transitions that have occurred to take it to its current state. For example, one obvious operation is cell division where a cell makes a replica of itself, and this can only occur when the internal counter is greater than a value associated with the gestation period of a cell. In our view, one model describes all cells, from those that are fully determined to those that are the most *plastic* (stem cells) that matches Theise’s idea that there may be no such thing as stem cells per se, but rather a range of different cell types which are simply more or less likely to behave in a *stem-like* way.

It should be clear from this description that scale plays no part in our abstract modelling of the properties of a stem cell. We are only interested in its behavioural properties and size and number or proportion of various cells is simply not considered. We do consider number and proportion though, and in our view also scale, when we move to a *simulation.*

In a simulation an algorithmic process is defined for each cell that will be in our initial world. Moreover, an environment is defined to contain a collection of all such cells and has certain basic physical, chemical and spatial properties. The advantage of simulations over wet laboratory work is that we can run a simulation of the whole system, as many times as we like using many different parameters and initial conditions. In comparison to traditional medical laboratory experiments, simulation is cheap and fast.

There are some basic properties we need for such a system including enough stem cells to ensure that the system will not die out, and to ensure that there is a constant production of the various determined cells that are required to replace cells dying in the human body. We also wish to show how such a system can restore some kind of equilibrium (return to stable proportions of the various cell types) after massive perturbations (modelling disease or injury). What we are particularly interested in, is whether this occurs in all situations. If not then it may simply be that the simulation does not contain enough cells to be sufficiently adaptable for the system to recover from a massive perturbation (such as that which occurs during cancer or Parkinson's disease).

More key than numbers, is to determine what fundamental properties of individual cells need to be modelled in order to see such adaptable behaviour at the global (system) level. Such adaptable behaviour is an example of emergence, which is a key one in our work and is especially attractive to the medical stem cell researcher Theise. For example, if we could show how a tiny environmental change, or a particular cell mutation would inexorably lead to a global system breakdown that compared to say leukemia, then it might suggest to Theise the kind of laboratory experiments he would need to conduct in order to look for early warning signs of certain diseases. It may even suggest ways in which the normal stable healthy system could be re-instated.

There has been a great deal of debate about what constitutes emergent systems, but they are typically described as having some kind of *order, structure* or *intelligence* that is not pre-determined. In our view emergence is related to scale and observation, and the conflict which arises between our different understandings at the micro- and macro-levels.

To address this we first consider the commonly-held belief of what constitutes emergence. The most commonly used definition of emergence is of a system whose "whole is greater than the sum of its parts'' (Odell 1998). Any simple reductionist argument though forces us to acknowledge that the whole is *exactly* the sum of the parts, for what else could it be? This is especially true in our simulation of the human body because everything is a set of initial conditions and behavioural rules, so there is a very clear sense in which everything is pre-determined and the consequence of this is that nothing is emergent.

What is missing here in order to understand the notion of emergence, and why it plays such a key role in the investigation of complex systems, is that the observer plays a critical role. In our view, emergence *only* exists with reference to an observer, and the reason that an observer views the behaviour of a system as emergent is because they cannot envisage how the innumerable interactions at the micro-level can lead to the observed system behaviour at the macro-level. To the observer, their perception of the overall system behaviour is unexpected or not anticipated and is therefore viewed as emergent. The observer interprets the system behaviour as emergent because they do not have a sufficiently detailed view of the processes and interactions that are occurring inside the system. Their observational frame is incomplete, and the observed emergent behaviours arise because they are based on issues that are outside the observer's comprehension. There is a conflict between the scales.

Scale plays a pivotal role in understanding and investigating emergence. We understand emergence as simply a surprising or unexpected observation at the macro-level. The element of surprise is because our expectations on a limited understanding of what was happening at the micro-level. This revelation means we don't have to comprehend *how* one tiny change in a cell or its behaviour may produce some global phenomenon. Just that the change takes place.

In fact we could not understand precisely the ramifications of each small change at the system level. However, we do wish to be able to switch between scales, from the micro to the macro, in a coherent way, as this is how we can see what changes at the micro-level result in specific desirable or catastrophic events to the stem cell system. The relationship between the micro and macro scale in CELL is essential to our understanding of emergence, which, in turn, is key to understanding the fundamental properties of stem cells and the adult human body.

## 5. Conclusions

We should make it clear at this point that the work of our team in investigating new theories of stem cell organisation and behaviour in the adult human body is still very much ongoing. An encompassing framework for expressing current mathematical models of stem cells, and our specific formal model of stem cell organisation based on Theise's novel ideas are undergoing further development. In addition, we continue to build different simulations of these visualisations to explore how best to build computational models that can have significance to a range of different audiences. It is also the case that further installations of art work based on this collaboration are in production.

Even though we are perhaps becoming more skilled at recognising when and where differences in our perception and understanding of a certain phenomenon arise and might arise, it does not detract from the creative process of trying to reconcile this conflict. Gaps in our understanding (shared or individual), are continually revealed to us through the process of collective sustained enquiry. Once those gaps are identified, the creativity comes in trying to provide whatever artefacts we can find; relationships, metaphors, processes, functions, images and so on, in an attempt to fill them. This is done *together,* and often for each other.

In this paper we have discussed some of the issues that continually arise whilst working on the CELL interdisciplinary project, looking at new theories of stem cell behaviour (d'Inverno 2004b, Theise 2003). The project developed as a result of us continually re-assessing our collective and personal positions in relationship to key concepts, as well as the working process itself. Only once a common language and framework for discussion and discourse was established and both individual and joint goals were clarified and collectively recognised, did the research find the momentum that has sustained the project for over two years.

There were many issues upon which we did not agree, and the three which were discussed more than any other were our differing notions of scale, the interpretation of images, and the understanding of what role emergence could play (which included us being very precise about the limitations of emergence in a computational simulation of a natural system).

There is no doubt that all of us benefited from working so closely together and we from gaining deeper understandings of the prejudices, assumptions and limitations of our own thought processes and languages that had become entrenched through our training and background in a particular discipline. As we became familiar with the thought and dialogue patterns of our collaborators, the efficiency and effectiveness of our communication grew to such a point that we became aware that gaps in our understanding could actually be harnessed to enable creativity. For example, is our impression that because neither of the authors had any biological or medical knowledge that we were able to think “out of the box” about how and why certain experimentally observed phenomenon might be occurring. There is certainly no doubt that through working with us both Theise has reconceptualised the way he thinks about stem cells – from dead tissue on a slide to a complex dynamic system. Through all this, conflict, and its exploration, was arguably the greatest catalyst in bringing about the success of this project.

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