

Dynamic hybrids and the geographies of technoscience: discussing conceptual resources beyond the human/non-human binary

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This paper discusses the nature of (post)-human and (post)-natural worlds by examining the types of entities responsible for knowledge production in contemporary technoscience. Based upon a case study in high energy physics and a constructive critical engagement with actor-network thought in science studies and geography, a complex trinity of geographically relevant actants is developed and discussed as a conceptual resource for studying geographies of human-environment relations beyond reductionist dualisms such as subject/object, nature/society and human/non-human. At the heart of the suggested trinity of actants lies the notion of 'dynamic hybrids' that identifies humans, other organisms and certain machines as decisive nodes between material and immaterial spaces of scientific network-building. The paper concludes by assessing how the suggested conceptual moves may affect the analysis and critique of scientific practice. It is pointed out that the proposed conceptual resources are not trying to establish new boundaries in order to contribute to a better understanding of science and its varying geographies, but to keep the categories we use in motion.

Key words: scientific practice, materiality, hybridity, immateriality, actor-network theory, physics

In the symmetry between humans and nonhumans, I keep constant the series of competences, of properties, that agents are able to swap by overlapping with one another. (Latour 1999b: 182)

Introduction

Over time many concepts have been developed about how humans position themselves within the known world. In the traditional Judeo-Christian view, for example, humans are autonomous from and superior to the natural world, and central to creation. As part of a God-Nature-Human trinity, they are entitled to help God ‘in finishing the task of creation’ (Jordon-Bychkov and Domosh 2002: 95), thus justifying a massive environmental transformation and the construction of all sorts of (bio)technologies that increasingly challenge traditional Human-Nature binaries. Quite different imaginations of and attitudes to human-environment interactions are implied by animistic and organic world views, which regard people as a part of and at harmony with nature but also allow for the possibility of what William Smole (1976: 23) phrased as an ‘easy transmutability [...] between what [we] commonly define as different realms: the human, natural, and divine.’

Such world views share common ground with recent works in science studies and geography that try to make sense of the diverse boundary-crossings, hybridities and contingencies produced by the rapidly expanding practices of the sciences and experienced in all spheres of everyday life (see, for example, Haraway 1997; Latour 1999b; Whatmore 2002). These studies often deal with conceptual resources developed in the wider context of actor-network theory (ANT), which emerged from sociological and anthropological studies of scientific practice in the 1980s and has substantially contributed to shifting the focus of geographical research to the role of

socio-material things and non-human organisms within human practices, interaction and culture.¹

In an attempt to replace the conventional but increasingly problematic *a priori* binaries of social theory such as subject/object, nature/society, micro/macro and inside/outside (Latour 1996; 1999b), actor-network based works introduced the idea of variable ontologies into scholarly debate by regarding every entity and category as a temporarily stabilised result of network-building processes between heterogeneous entities (Latour 1992: 286). The categories of humans and non-humans, however, remained intact when addressing the resources and outcomes of network-building (see, for example, Latour 1993: 11, 134; 1999b: 304), implying what Sarah Whatmore (2002: 165) refers to as a ‘residual humanism’ and running the risk of becoming black boxes of their own.

These observations inevitably raise two questions about conceptual ideas that currently inform much research in geography and other fields of the social sciences: Why is it that even in an approach which has repeatedly been labelled ‘anti-humanistic’² the category of the human is still so powerful? And – re-phrasing a question brought up by Noel Castree and Catherine Nash with regard to this theme issue – what form may conceptual resources take when one cannot readily speak of the ‘social’ and the ‘natural’, the ‘human’ and the ‘non-human’?

In this paper, I would like to take up these questions by exploring recent practices and geographies of knowledge production in contemporary technoscience and by discussing their conceptual implications in the light of ANT and its contested history within science studies and geography. By developing the notion of ‘dynamic hybrids’ as nodes of scientific network-building, I would in particular like to argue that this concept, when seen as part of a ‘trinity of actants’, may not only contribute to

a better understanding of how geography matters in the production of scientific knowledge, a topic raised by David Livingstone's (1995; 2002; 2003) outline of a geography of science, but may also help to gain a sense of conceptual orientation over changes taking place in what has been discussed as our emerging post-human and post-natural worlds (see, for example, Hayles 1999, Fukuyama 2002, Castree and Nash 2004).

In a recent exchange on the meaning of interdisciplinary debates about 'post-humanism' for geographical discourse and practice (see Badmington 2004, Braun 2004, Castree and Nash 2004, Murdoch 2004, Whatmore 2004), Noel Castree and Catherine Nash identified three prominent lines of argument. According to their review, the first line of argument, exemplified by Francis Fukuyama (2002), regards the post-human as an '*historical condition*' in which non-human technology-based beings would dominate the human realm in the long-term. The second line of discussion sees post-humanism 'as a set of *ontological theses* about the human that never was and will never be' (Castree and Nash 2004: 1342), which is a discourse that applies Bruno Latour's (1993) argument 'We have never been modern' (and thus have never been post-modern) to similar debates on nature and the human. The third line of post-humanist thinking, practised, for example, by Neil Badmington (2004), could be understood as a "'both/and" form of *deconstructive reading*' that 'takes the form of a ceaseless scepticism about the claims made in the name of either the human or its notional transcendence' (Castree and Nash 2004: 1342).

Against this background, the following remarks subscribe to an analytical-philosophical position that builds upon actor-network-based ideas of gradual, unpredictable shifts in power-relations between non-human nature, humans and technologies (Latour 1993; 1999b). While following Sarah Whatmore's (2002; 2004:

1361) call for ‘more-than-human’ geographies, it applies a form of *critically constructive reading* to both conceptual debates and empirical realities by exploring how a geographical perspective on recent developments in technoscience might contribute to conceptual resources that overcome restrictions imposed by conventional binaries of social theory. On these grounds it is assumed that post-humanist thinking prepares neither for ‘the end’ of humans nor for ‘the end’ of suggesting conceptual resources that might help to make sense of human-environment relations in different times and places. My motivation for exploring such conceptual resources is in fact based on Bruno Latour’s (1999c: 24) call for continuing to develop ANT’s ‘strange potential’ in a collective endeavour. It can also be regarded as an attempt to tie in with Noel Castree’s (1995: 41) recommendation ‘to dissect the complexity’ of the category ‘nature,’ and ‘to develop a more sophisticated [...] vocabulary’ for dealing with issues of materiality and knowledge production in geographical research.

Argumentation

The first part of the paper briefly sketches one possible reading of ANT and its history within science studies in order to provide the background for the conceptual moves suggested in the third part of the paper. While it is well known that actor-network thought is a heterogeneous, ever-evolving and contested project that has been developed and elaborated in quite different ways by Michael Callon, Bruno Latour and John Law since the mid-1980s (see, for example, Callon 1986; Callon, Law and Rip 1986; Law 1986a; 1994; Law and Hassard 1999; Latour 1987; 1993; 1999b), the introductory remarks concentrate on a particular exchange between David Bloor and Bruno Latour that specifically deals with the geographically significant question of

how nature, society, knowledge and technology can be understood and how they are interrelated (Bloor 1999a; 1999b; Latour 1999a). By positioning both empirical findings and conceptual reflections within the Bloor-Latour debate, I would like to suggest that their arguments appear in a quite different light when placing a geographical perspective on scientific practice and interaction.

Interested in the meaning of space within the process of knowledge production, such a geographical perspective is applied in the second part of the paper, which examines recent practices and geographies in the field of high energy physics. The presented case study was chosen from a larger project on the geographies of different scientific practices, in which I interviewed 85 US researchers from across the sciences and the humanities in order to gain a better understanding of their travel and collaborative cultures (Jöns 2003). In this paper, the focus is on high energy physics as this is a well documented and rapidly changing branch of the technosciences (see, for example, Crane 1971; Traweek 1988; Krige 1993; Knorr Cetina 1999). By constructing and using sophisticated technologies in order to extend humans' sensory perception to times and spaces that would otherwise remain inaccessible, high energy physicists profoundly challenge familiar understandings of space, agency and other basic categories of social theory such as 'nature,' 'human,' and even 'god,' a fact that has strongly contributed to the impression of an emerging post-human, post-natural and post-divine world in the twentieth first century.

The third part of the paper translates the empirical findings into theory by reflecting upon the meaning of the 'human' and the 'non-human' in high energy physics. Based upon a constructive critical engagement with the Bloor-Latour debate, comments on actor-network thought by other science students and the empirical findings, it is argued that ANT's proclaimed conceptual symmetry between human

and non-human ‘actants’ leads to some blind spots in the analysis of network-building processes. Alternatively, the notions of ‘dynamic hybrids’ and a ‘trinity of actants’ are developed and put up for discussion. The paper closes with addressing some of the ways in which the proposed conceptual moves may affect the analysis and critique of scientific practice and human-environment interactions more generally, thus building a bridge to the other contributions in this theme issue.

The Bloor-Latour debate

The idea that geography matters in the production of scientific knowledge began to take shape in the 1970s when science studies questioned an immanent universality of scientific content by arguing that knowledge reflects various social interests of those who propose it (Barnes 1998: 205). Up to that point, truth about natural reality was regarded as being self-explanatory and not influenced by the social environment, whilst false beliefs were explained by social factors that could only hinder scientific inquiry (Merton 1942; see also Latour 1993: 92).

Among those who first rejected this rationalist approach to science, were the followers of the Edinburgh school of social constructivism (Barnes 1974; Bloor 1976). Based on empirical case studies, David Bloor argued that ‘[b]oth true and false, and rational and irrational ideas, in as far as they are collectively held, should all equally be the object of sociological curiosity, and should all be explained by reference to the same kinds of cause’ (Bloor 1999a: 84). By explaining shared beliefs about nature on the basis of this so-called ‘symmetry postulate’, the role of social interests and requirements for the production of scientific knowledge became the centre of interest of a sociology of scientific knowledge.

Since the late 1980s, actor-network theorists have promoted an alternative approach to the project pursued by social constructivism (see, for example, Latour and Woolgar 1986; Latour 1987; 1993). Although they emphasise that it overcomes the epistemologists' asymmetrical approach of explaining falsehood with social factors and truth by natural reality, Bruno Latour accuses this 'first principle of symmetry' of also being asymmetrical, because 'it brackets off Nature and makes the 'Society' pole carry the full weight of explanation' (Latour 1993: 94).

Instead of trying to explain nature in terms of society, society in terms of nature, or knowledge as a mixture, actor-network based approaches conceptualise scientific practice as a network-building process between heterogeneous entities and thus reject all *a priori* binaries. Scientists, research objects, technical infrastructure, sponsors and all other human and non-human entities involved in scientific practice are regarded as being outcomes *and* mediators of network-building and thus, as human agency is extended to things, are equally considered to be 'actants'.

ANT suggests following or reconstructing network-building processes between different actants in order to trace their connections and to understand the stabilisation process and variable ontologies of the emerging categories, scientific black boxes and new actants (Latour 1987; 1996). By arguing that humans and non-humans should be treated symmetrically in such an undertaking, ANT's much-quoted 'generalised principle of symmetry' (Callon 1986: 200f) directed the main focus towards the role of previous neglected socio-material things needed to construct and stabilise scientific knowledge and other 'social' structures.³

In the course of the last two decades a strong opposition between social constructivist and actor-network based approaches to science has developed which has culminated in an exchange between two main advocates, David Bloor and Bruno

Latour, on the meaning of knowledge, nature and society for scientific work (Bloor 1999a; 1999b; Latour 1999a). While both agree on arguing against rationalist and natural realist positions, Latour criticises social constructivists for not being interested in the role of objects for knowledge production. He wonders how social interests and requirements could arbitrarily produce biology, chemistry and the cosmic order (Latour 1993, 55), and argues that ‘the Edinburgh daredevils deprived the dualists – and indeed themselves [...] – of half of their resources’ (Latour 1993: 55).

In turn, Bloor misses the role of shared, institutionalised and other forms of knowledge within ANT. He replies: ‘[T]hroughout the entire discussion, Latour makes no systematic distinction between nature and beliefs about, or accounts of, nature. [...] It is as if he has difficulty telling these two things apart’ (Bloor 1999a: 87). Steven Shapin pointed in a similar direction when identifying the paradox that Latour’s account of technoscience displays ‘a world in which anything and anybody can be an actant or an actor, where we may [...] speak of texts but not people as having independent interests’ (Shapin 1988: 547).

Comparing these arguments reveals that actor-network thought introduced new explanatory resources to science studies by looking at the ways in which socio-material things act upon humans. However, its strong rejection of social constructivism has been mutually linked with the neglect of explanatory resources pivotal to this approach, namely social interests, mindsets, goals, feelings and knowledge. These are as much invested in scientific practice as money, collaborators, research objects and infrastructure (Shapin 1988: 543) and thus are *actants* themselves.

Against this background, I would like to show that the types of explanatory resources stressed in each approach imply different geographies of scientific practice

and thus should all be considered in order to account for the meaning of space in scientific work. What this means for conceptual resources that go beyond the human/non-human binary will eventually become clear after discussing the empirical example of recent practices and geographies in high energy physics.

Creating new spaces

The field of high energy physics originated in the first half of the twentieth century when researchers began to study nuclear reactions and the structure of new-found particles with the help of linear and circular particle accelerators (Knorr Cetina 1999: 159-166). At the beginning of the twenty-first century, large particle accelerators achieving high energy levels can be found in about seventy places (Frommberger 2005). Half of these facilities are located in Europe, including the *Centre Européen pour la Recherche Nucléaire* (CERN) at Geneva, which is the world's largest particle physics laboratory today (CERN 2004).

In the early 1990s, a major change in the history and geography of high energy physics was triggered by the development and construction of the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory on Long Island, New York. This particle accelerator, which began operation in 2000, comprises of two counter-circulating rings with a circumference of 3.8 km, enclosed in a tunnel about four meters underground. At the rings' intersection points, the nuclei of heavy atoms such as gold are smashed together at nearly the speed of light, primarily to create a form of matter, the so-called quark-gluon plasma, that is supposed to have existed ten millionths of a second after the Big Bang, i.e. at the dawn of our universe, about 13.7 billion years ago (NASA 2004, BNL 2004). While constructing a post-natural world *par excellence* when colliding particle beams inside the RHIC tunnel, the physicists'

ambitious practices of re-modelling what comes close to the act of the known world's (probable) creation, begin to blur the boundaries between what has been conventionally designated as the separate domains of Gods and Humans.

In their efforts to generate new data and knowledge about the origins of our universe, RHIC physicists rely on four highly developed particle detectors that Sharon Traweek (1988: 17) considers to be 'the key informants' of such a study (figure 1). Located at the points where the two rings of accelerating magnets intersect, these huge detectors are able to witness and record the events performed by colliding particle beams and to translate the fleeting signals of sub-atomic interactions into a scale and language accessible to humans. Extending the researchers' senses to extremely small, dense, short-lived and hot physical spaces,⁴ this extraordinary mediation is only possible by combining basic human characteristics such as the materiality of the human body with the skills of observation, translation and representation. By using detecting elements, memory devices and powerful computers to pursue their ascribed tasks, the particle detectors incorporate what could be regarded as a post-human version of an embodied mind. Thus, they are resembling what I will later conceptualise as 'dynamic hybrids', i.e. entities who are able to actively negotiate between the realms of matter and meaning because their abilities are based on a dynamic combination of both.

Figure 1 about here

The individuality of those four detectors operating at RHIC results from different strategies of their constructors, manifested in the language and skills they were taught and in the quality of their constituting socio-material networks (Traweek 1988). Accordingly, these detectors form the nodes of four competing collaborative experiments named STAR, PHENIX, PHOBOS and BRAHMS. Praised in a press

release as a ‘nice example demonstrating that science has no borders’ (AIP and APS 2000), a closer look at the collaborative patterns of about 1,000 researchers working in 100 institutions across eighteen countries reveals distinct spaces of exclusion, co-operation and competition (figure 2a). Excluding those people, institutions and places that cannot afford what Bruno Latour (1987: 179) described as the ‘expensive proof race of the sciences,’ the few regional clusters of participating institutions mirror a 30-year-long history of interaction within the specialised field of relativistic heavy ion physics.

Forming networks

The field of relativistic heavy ion physics started in the early 1970s when the BEVATRON, the former synchrotron at the Lawrence Berkeley National Laboratory (LBL), was converted to the BEVELAC in order to accelerate heavy ions at two orders of magnitude higher energy than previously possible (Westfall 2003). The machine’s conversion attracted researchers from Germany and from Japan who were hosted by two different research groups at the BEVELAC, thus forming two different collaborative networks in the 1970s.

Since that time, the field’s centre of activity has shifted in accordance with the emergence of new facilities operating in ever higher energy ranges, namely from the BEVELAC to the CERN in the mid-1980s and from the CERN to the RHIC in the late 1990s. A comparison of the geographies of the participating institutions in the large experiments conducted at CERN in the early 1990s and at RHIC in the late 1990s reveals, first, how the experimental networks became ever more transnationally organised, at least within the Northern Hemisphere (figure 2). This development is mainly related to the experiments’ ever-expanding complexity and costs requiring

more and more people with different expertise as well as increasing financial contributions from national governments and other sources. Other influencing factors are the fields' growing history and popularity based on scientific results that are at the cutting edge of the sciences.

Figure 2 about here

Secondly, the changing geographies of scientific collaboration highlight the lasting importance of regional clusters next to the research facility and – as the examples of India, China, Korea and Japan concisely illustrate – of national clusters in competing experiments, primarily for reasons of funding, accessibility, research styles and personal ties. According to one of my interviewees, the Japanese cluster of participating institutions in the PHENIX experiment can be attributed to the initiative of a single researcher by the name of Shoji Nagamiya. Nagamiya worked at the BEVELAC for a couple of years, became a professor at Columbia University and eventually went back to Tokyo University. As one of the proposers and a former spokesperson of what became the PHENIX experiment, he interested a large number of Japanese scientists in RHIC physics, while his home country 'invested about 20 million dollars into particular equipment at RHIC and formed a [PHENIX] analysis-computing centre in Japan' [Interview 82].

Thirdly, these mappings support the experience of the first BEVELAC director that 'the groups of collaborators formed at one accelerator tend to stay together even when they move to different experiments' [Interview 39]. The Americans with him in CERN experiment NA49, that is UCLA and Seattle, are also in the STAR experiment. The same is true for the group of his long-term collaborator Reinhard Stock from the University of Frankfurt, who initiated the German-American

collaboration at the BEVELAC with a visit to Berkeley in the mid-seventies and later became the spokesperson of CERN experiment NA49.

By increasing the mutual trust necessary for the development of working routines and an open, scientifically rewarding exchange of ideas and materials, the history of shared experiences, practices and responsibilities in high energy experiments has contributed to the formation of relatively stable collaborative networks that are working together to find new phenomena against the other collaborations, while continually reproducing themselves:

They persist for a long time these things... People recommend their students and post docs to their collaborators and this is the network that keeps on going.

[Interview 39]

Accordingly, the Japanese-American network in the PHENIX experiment at RHIC is somewhat separate from the German-American network in the STAR experiment, and – as the former BEVELAC director illustratively put it – ‘there’s been no crossing over between them’ [Interview 39]. While the STAR collaboration at RHIC gave credit to its name because it was more or less approved as proposed by the collaboration centred around the LBL and other people previously engaged in the CERN experiment NA49, the second large experiment at RHIC, PHENIX, emerged out of the ashes of four proposals that originally got rejected, thus being a merger of collaborative networks that had been part of the CERN experiments NA44, NA45 and WA98. The origins of the collaboration, however, can still be identified by tracing the name of Shoji Nagamiya from his involvement in the Japanese-American group at the BEVELAC to the PHENIX experiment at RHIC.

While the different experimental networks expanded considerably over the years, the outlined genealogies of two large RHIC collaborations show that these are based on small and productive experienced teams, which are coherent enough to survive the move from one accelerator to another, thus resembling what has been described as *invisible colleges* (Solla Price 1963; Crane 1972):

Our colleagues at Frankfurt and Munich together with us developed expertise on the time projection chamber... So there was a core that came from NA35/NA49, who had developed technical expertise and had an interest in a particular style in doing physics, and when it became time to propose STAR, these people came on board. [Interview 82]

Localised by the corporeality of the collaborating researchers and their equipment, those invisible bonds and intangible actants relating to memories of previous encounters, personal ties, ‘a style of doing physics’, trust as well as competition shape the geographies of the RHIC community as much as socio-economic conditions in different countries and the accelerator itself (figure 2a).

Negotiating (im-)materialities

Being firmly anchored in the ground of Long Island, New York, the accelerator becomes an obligatory passage point at early stages of scientific network-building. When data on heavy ion collisions is generated, most of the collaborators travel to Brookhaven for the time of the experiment:

I probably go ten times a year or 15 times a year [to Brookhaven]... In order to be connected to the science you absolutely have to be there, have your hands on, see what's happening. There are immediate decisions to be made: Do we configure the detector this way, do we configure it that way? ... Every data taking period is different, there's new equipment, there's things behaving differently... So when the data are being taken... it's absolutely essential to be there at least for a part of the time in order to really understand what's going on.

[Interview 82]

The data analysis and the paper writing, however, are usually done at the researchers' home institutions. In the form of notes, files and memories, the necessary data resources can easily be transferred to those places providing the basic infrastructure for constructing a stable interpretation out of the experimental data. Continued collaboration at a distance is based on the fact that the highly abstracted nth-order representations of experimental practices and products involved in the data analysis and paper writing are ontologically compatible with the virtual realm of modern telecommunication media and thus can be transferred back and forth electronically without being changed too much:

Every week, on Monday at one o'clock... we have a physics analysis conference for about an hour... It's always Berkeley, UCLA, Texas, Brookhaven, some of the East Coast institutions, I phone Sao Paulo and Calcutta; people call in from Birmingham; actually we have some Dutch people now... some people call in sometimes from Germany and occasionally I have to call someone in Russia... Basically, what you do is you put your results on the web and everyone can get

them instantly... Everyone uses the Internet, five minutes before the meeting they can download the figures and at the phone meeting you just say go to my area, there's a new thing, and it all works fine. [Interview 82]

These different forms of intense traffic between RHIC and the participating institutions help to maintain the comprehensive collaborative networks of knowledge production over large distances. They reveal that human interactions can be stabilised and extended through time and space in at least three ways. The first way involves the transfer of socio-material non-humans (immutable mobiles, quasi-objects, inscriptions) as stressed by actor-network based studies (see, for example, Murdoch 1997b: 327), the second way refers to the use of memories by travellers and the third way represents electronic transfer of information.⁵ When thinking in terms of concepts, however, it is not clear how immaterial entities such as memories and electronically conveyed meaning, knowledge, ideas, interests, goals and feelings integrate into the binary concept of human and non-human actants according to which both should be treated symmetrically when analysing how networks are built, how new actants emerge and how power is distributed among different actants (Latour 1999b: 182; figure 3).

Figure 3 about here

While the sketched Bloor-Latour debate indicated that the proclaimed symmetry of humans and non-humans does not sufficiently account for the role of knowledge and ideas in scientific practice, many critics of ANT have been aware of the fact that although '[m]etaphors and discourse are, of course, a vital part of scientific practice' (Demeritt 1996: 489, referring to feminist critiques of ANT), the repertoire of actor-network thought does not account for the 'role of knowledge in linking scientists

together' (Murdoch 1997a: 752, summing up different critiques). Nigel Thrift pointed in a similar direction by arguing that 'actor-network theory cannot speak of certain things' (Thrift 1999: 313), including aspects such as 'emotion', 'memory', and 'language' (Thrift 1999: 314-316).

Against this background, the proclaimed conceptual symmetry of human and nonhuman actants appears to be problematic as what is referred to as human means much more than what counts as non-human (figure 4). In most writings on ANT, non-humans always seem to belong, at least partly, to the material world (see, for example, Latour 1993: 79, 138; Bingham 1996: 643-647). Humans, however, not only show this (socio)materiality, which is vividly expressed in the human body, but they are also able to deal with thoughts and feelings, ideas, knowledge and other memories, all of which have been identified in this paper – conceptually as well as empirically – as actants themselves. Thus, I would like to suggest that the concentration of actor-network based science studies on the previously ignored role of matter in scientific work has led to the neglect of the mediating role of what could be addressed as mental, virtual and immaterial entities. These were mainly 'blackboxed' under the label 'human' but also – as the example of the translating particle detector showed – overlooked in parts of the non-human realm.

Figure 4 about here

In order to disentangle what is happening on the side of 'humans' and 'non-humans', my first of three conceptual suggestions is, therefore, to acknowledge materialities and immaterialities as distinct types of actants when trying to make sense of scientific practice and its geographies. Since the concepts and terms at hand do not only shape research interests and methods in a certain time and place, but also suggest what counts as important and who is allowed to be heard, I do not think that it would

be sufficient to be content with the mere possibility of considering aspects like ideas, emotions and subjectivity within a diffuse set of actor-network ideas (Hitchings 2003). In the case of mental and other immaterial actants it seems to be even more important to acknowledge their power conceptually, because due to their invisibility, they are always in danger of being ignored by the simple observer of scientific practice. Representing an immaterial counterpoint to socio-material non-humans, mental actants are necessary to transform matter into signs and to recognise the meaning of these signs. They themselves are collectively produced and altered in the course of network-building, but, as the case study in high energy physics exemplified, they imply different scientific geographies to their material counterparts – for example, in regard to invisible colleges and collaboration at a distance.

Introducing dynamic hybrids

One important way in which material and immaterial actants shape the spaces of science differently relates to the changing meaning of (im)materiality in the course of knowledge production. This process, that alters the geographies of the RHIC community all along, can be best described by what Bruno Latour conceptualised as reversible chains of transformation between an analogue world at the one extreme and ultimate abstraction at the other (Latour 1999b: 70-71). According to this concept of ‘circulating reference’, scientists perform consequential mediations from matter to form in order to generate comprehensible and well communicable scientific claims about much more complex phenomena (figure 5a). As long as all steps are traceable in both directions, these chains tell how knowledge claims came into being and thus, representing Latour’s answer to basic questions of epistemology, they transport truth (Latour 1999b: 69). Latour points out that each mediation means a trade-off between

the loss of multiplicity, particularity, locality and materiality and the gain of standardisation, compatibility, circulation, relative universality – and what I would like to add – immateriality.

Thus, following the cascade of knowledge production in the RHIC community from the construction of the accelerator and its detectors via the particle beams' collisions, the data taking period and the modelling of the detector response to the data analysis, the discussion of first results and the editing process of a paper (figure 5b), the scientists' needs and possibilities to reach out from a place of knowledge production in order to communicate and to mobilise new resources in different places vary considerably according to the constitutive entities at different stages of their work. This is because they deal to a varying extent with material and immaterial entities that imply different geographies respectively. In short, dealing primarily with material entities, such as the constitutive devices of the accelerator, may tie the researcher to a particular spatial setting, while immaterial entities such as knowledge, recorded data, calculations and arguments do not necessarily show any other physical manifestation than the corporeality of humans, computers, paper forms or other media, and thus they are as mobile as their physical vehicles allow them to be.

Figure 5 about here

Therefore, the suggested differentiation of material and immaterial actants may serve to conceptualise one particular way in which geography matters in the pursuit of science. The related conceptual move, however, raises the questions of how these two types of actants are tied together, and which role humans play within the heterogeneous networks of particle beams and knowledge claims, sub-atomic events and multinational collaborations, detectors, hopes and potential Nobel Prizes as encountered in the world of the RHIC community.

Latour developed his concept of ‘circulating reference’ between words and the world in order to expose two failures of the modernist settlement – the differentiation of two ontological domains of language and nature, and the search for correspondence over the huge gap that separates them. He argues that through the erasure of all the traceable connections between the object of knowledge (nature) and its representation (language) the two non-existing ontological domains and the separating gap of the modernist settlement came into existence (Latour 1999b: 73). According to Latour, however, ‘circulating reference’ is characterised by ‘a complete rupture at each stage between the “thing” part of each object and its “sign” part’ (Latour 1999b: 60). Hence, he illustrates the rupture with question marks, indicating that it is a complete mystery what happens during each transformation from matter to form (figure 5a).⁶ While the answer to the question of *what* actually happens in such an individual transformation may indeed be a complete mystery, I think that there is no mystery at all about *who* does the transformation and thus bridges the presumed gaps between things and signs. This is because every gap between world and words is closed by practices and performances of what I propose to call ‘dynamic hybrids,’ i.e. beings that are able to negotiate between matter and meaning because their abilities are based on a dynamic combination of both realms.

In the first instance, dynamic hybrids are humans such as the experimental high energy physicists. Combining the socio-materiality of humans and non-humans with the ability to deal with all sorts of mental and other immaterial entities, humans are able to transform matter into signs and to recognise the meaning of signs (figure 6). Understanding human actors as beings in which different types of actants are dynamically linked together and that, in turn, actively tie together other actants, it becomes obvious that their abilities, because of the combinational power, are

ultimately greater than those of singular immaterial and (socio)material actants. At least, this is true until the dynamic circulation between ontologically different components, which keeps us alive, ceases to exist, and we are reduced from human beings to non-dynamic socio-material matter.

Figure 6 about here

My second conceptual suggestion is, therefore, to differentiate between at least two meanings of hybridity in the context of actor-network thought: first, classical socio-material or historic hybridity in terms of a hybrid historicity resulting from the involvement or ‘socialisation’ of matter into human interaction. Second, dynamic hybridity understood as an extremely *dynamic combination* of different types of actants in the realms of matter and meaning that facilitates dynamic hybrids to actively negotiate between ontologically different elements and to establish lasting connections between them. Derived from Latour’s concept of circulating reference, this notion of dynamic hybridity is also intimately related to Henri Lefebvre’s concept of the ‘living body’ that he uses in order to underline the problematic nature of the subject-object polarity in social theory: ‘The living body, being at once “subject” and “object”, cannot tolerate such conceptual division’ (Lefebvre 1991: 407).

Despite humans being the most complex dynamic hybrids in the known world, they are, however, not the only ones by far. On the one hand, humans are certainly not the only organisms on earth capable of producing and interpreting signs. In anthropology and geography, for example, recent works by Ingold (1988), Philo and Wilbert (2000) and Whatmore (2002) explore the constructions, knowledge, and consciousness of non-human animals and other non-human life forms, as well as the relationships between humans and non-human animals. Within ANT, however, other-than-human organisms are lumped together with inanimate objects under the label

‘non-humans.’ This raises the question whether inanimate objects and other-than-human organisms can in fact be treated equally when analysing network-building processes, or if this concept implies an unpropitious human-centred perspective, which ANT originally strived to overcome.

On the other hand, following Donna Haraway (1997: 126-127), the argument that only organisms are sign interpreters may have been valid in the 1930s. As of the 1990s this is no longer true as machines have been developed that are capable of communicating and interpreting signs too. This is particularly the case for contemporary technoscience in which scientists rely on sophisticated technologies such as supercomputers and accelerators when charting new intellectual and physical territory or maintaining close collaborations and widespread invisible colleges at a distance. The observation that human skills can increasingly be found among technical devices and often go much further in certain areas is not only underlined by the four detectors operating in the RHIC facility, but also by a broad range of literature on new technologies, artificial intelligence, Donna Haraway’s ‘cyborgs’ and new forms of artificial life which can be traced in different academic fields (see, for example, Turkle 1985; 1997; Haraway 1991; 1997; Hinchliffe 1996; Crang, Crang and May 1999).

Accordingly, the notion of ‘dynamic hybrids’ comprises of humans, animals and other organisms as well as certain machines such as robots and computers. If running, the latter help scientists to extend their senses and skills considerably and to open up new spaces for scientific inquiry (the latest example being the Exploration Rovers that landed on the planet Mars in 2004). Although they are equipped with very different abilities, what all dynamic hybrids have in common is a *continuous circulation* providing a dynamic connection between their material, immaterial and dynamically

hybrid components and thus a greater scope of negotiation than non-dynamic actants can use for network-building. My third and final conceptual point is, therefore, to be aware of the difference between non-humans and non-human dynamic hybrids when trying to understand the geographies of network-building processes and to evaluate their chances and dangers.

Sketching a complex trinity of actants

As a result of the conceptual moves derived from exploring the geographies of technoscience, I would like to sketch a different concept of actants to the conceptual symmetry of humans and non-humans and suggest that this may better account for different scientific practices and their geographies. This trinity of temporarily differentiable actants identifies human beings alongside other organisms and certain technologies as dynamic mediators between material entities on the one hand and immaterial entities on the other hand, including their historically hybrid variations (the boundaries between those realms, however, become blurred when one tries to separate them accurately). Materialities, which always incorporate some kind of information (see, for example, Serres 1995), represent the world of matter, things and non-dynamic (socio)materialities. Immaterialities, which in turn are always embodied in some kind of physical vehicle (see, for example, Lakoff and Johnson 1999), incorporate the world of thoughts, imaginations, memories, feelings, (shared) meaning(s), concepts, social conventions, ideologies, instincts and the virtual reality.

Figure 7 about here

These three types of geographically relevant actants could be further sub-classified, thus constituting a complex trinity of actants in which differences are rather gradual than substantial (figure 7). Building upon the concept of actants as outlined by

ANT, all types of actants can incorporate a historicity that could be ontologically hybrid and share the responsibility for further events. Nevertheless, the involvement of humans or other dynamic hybrids is indispensable for socialising materialities and materialising immaterialities. They are the agents that keep scientific network-building going, thus producing knowledge as well as scientific histories, geographies and biographies. They are also responsible for creating new post-human and post-natural realities that may one day be so well constructed that they start to dominate the human world, just as Nature seems to have constructed Humans that later dominated her realm – even if this does not have to be the case in terms of a teleological view as it has been criticized in recent debates on post-humanist thought (see, for example, Badmington 2004, Braun 2004, Castree and Nash 2004).

Drawing upon actor-network based writings, the power-relations between humans, other organisms and technologies can be considered as gradually shifting in unpredictable ways. At this point in time, however, the use of certain mental constituents, especially the ones involved in scientific practice, and the related ability to enlist other entities for their purposes enable humans in many situations to build more powerful networks than organisms or machines can do. While this in fact makes the category of the ‘human’ very prominent in most conceptual accounts, including actor-network theory, it does not contradict the possibility of much more ambiguous power-relations when studying particular network configurations (see Whatmore 1999: 28-29):

The use of computers has opened some parts of our field that previously were just too difficult to calculate, and now computers are able to handle all these things. It still takes good ideas and unfortunately the use of computers is something that has plus and minus attached to it... I mean the ideas are crucial,

so a computer is important but it's not the critical driving thing. In some other areas it's essential – I would say for my experimental colleagues it's completely critical. These very large experiments done at the modern laboratories ... [have] so much information to be handled that it requires state of the art computing.

[Interview 10]

Finally, the suggested concept of a complex trinity of actants relates to the idea that the meaning of different types of actants for network-building processes substantially varies in time and space, thereby complicating the static picture given in figure 7 in at least two ways: In the historical dimension, the spectrum ranges from a dominance of materialities at the dawn of our universe – nicely illustrated by the case study on the attempt to (re-)create a quark-gluon plasma – to a growing significance of immaterial and virtual worlds in the age of the Internet. In the spatial dimension, however, variations can always be observed between individuals and groups of people, whose practices, while situated in culturally hardly transformed environments, are dominated by material concerns, and those, while primarily operating in culturally strongly transformed areas, are much more shaped by imaginations and symbolically charged socio-materialities. In the context of high energy physics, such variations in time and space have been identified in the changing meaning of (im-)materialities for different stages of scientific work as well as in the difference between participating researchers in the centres and the peripheries of large collaborative networks and those who are lacking the necessary material and immaterial resources to participate at all.

Conclusion

In this period of what has been described as our emerging post-human and post-natural worlds, research practices in the natural and technical sciences increasingly challenge conventional categories of social theory such as subject/object, nature/society and human/non-human. In this paper, I began with an investigation of conceptual resources that may be suited to account for these developments by applying a geographical perspective on scientific work and *interaction* and by discussing related empirical findings in the context of what Latour (1999b: 294) refers to as his conceptual *bricolage* on the reality of science and its studies.

Based on an empirical case study in high energy physics, a constructive critical engagement with a conceptual debate between David Bloor and Bruno Latour and other comments on actor-network thought in science studies and geography, I argue that an actor-network based conceptualisation of scientific practice as a network-building process between heterogeneous entities is crucial for understanding geographies of technoscience. Applying the perspective of geography to scientific practice and interaction, however, revealed that the binary terms of ANT's proclaimed conceptual symmetry between humans and non-humans do not only imply some blind spots in the empirical analysis of actor-networks but also seem to be trapped by the Cartesian dualism that it originally strived to overcome.⁷

As a contribution to ongoing debates on (post-)humanism and related discourses on human-environment relations, I would like to propose for discussion the notion of 'dynamic hybrids' as decisive nodes between the material and immaterial spaces of scientific practice and interaction and to suggest that the resulting complex 'trinity of actants' may provide conceptual resources that begin to overcome restrictions imposed by dualisms such as natural/social and human/non-human. While combining

poststructuralist thinking with the role of materialities and immaterialities for network-building processes, the proposed complex 'trinity of actants' extends the notion of an embodied mind to the corporeality of humans, other organisms and certain technologies and thus could be regarded as a conceptual synthesis of ongoing discussions in science studies and different branches of geography.

Leading to an expansion of perspective and an increase in complexity, all three basic types of geographically significant actants should be taken seriously with regard to their potential effects. This implies that each of them could be used as a possible starting point for empirical analysis as much as for modifications and related political, socio-economic, organisational, technical or environmental change. Regarding the Bloor-Latour debate, the proposed conceptual resources may offer a possibility to integrate the foci of social constructivist and actor-network based understandings of the sciences. In the context of empirical science studies, they may provide the means for extending the notion of scientific practice as a network-building process between heterogeneous entities from technoscience to theoretical work and the humanities (Jöns 2003: 156-160).

In the end, it is important to note that the proposed conceptual resources do not try to establish new stable boundaries in order to contribute to a deeper understanding of the technosciences and other empirical contexts that escape traditional understandings of nature and society, the human and the non-human, but to keep the categories we use in motion (Latour 2002: 21). Considering the scientists' ambitious efforts to conquer domains conventionally designated to 'God' by re-modelling what comes close to our universe's (probable) origins and by creating new types of (bio)technological beings, it seems that studying the geographies of scientific work and interaction in different academic fields may provide many more opportunities to

further engage with Bruno Latour's question about possible links between the four conventional but increasingly problematic *a priori* categories of what he calls 'the modernist settlement' – namely Nature, Society, Mind and God (see also Latour 1999b: 14):

ANT is not a theory of the social, any more than it is a theory of the subject, or a theory of God, or a theory of nature. It is a theory of the space or fluids circulating in a non-modern situation. What type of connection can be established between those terms, other than the systematic modernist solution?

This is, I think clearly the direction of what is 'after' ANT. (Latour 1999c: 22)

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Notes

1 In particular, this body of work informed the conception of relational geographies (see, for example, Bingham 1996; Bingham and Thrift 2000; Murdoch 1997a; 1997b; Thrift 1999; Zierhofer 1997), discussions on the understanding of humans, nature and culture (see, for example, Castree 1995; Whatmore 1999; 2002; Zierhofer 1999; 2002) and case studies in different empirical contexts such as science and technology studies (see, for example, Barnes 1998; Bravo 1999; Demeritt 1996; Hetherington and Law 2000; Hinchliffe 1996; Jöns 2003; Livingstone 1995) and economic geography (see, for example, Murdoch 1995; Jöns 2001).

2 On ANT's opposition to humanism, see, for example, Latour (1993: 136-138; 1999b: 3, 17-19). For critical comments on the role of humans in ANT see, for example, Collins and Yearley (1992) and Pels (1996). Murdoch (1997a) and Whatmore (1999) discuss the 'human' in human geography within the context of ANT's 'anti-humanism.'

3 According to the 'generalised principle of symmetry' human and non-human actants can both have their own historicity, an ontologically hybrid status and a potential responsibility for further action. Although the symmetry principle refers to the ways in which analysis should proceed, it does not imply that the power-relations between different actants are equal or non-hierarchical (see Hetherington and Law 2000; Hitchings 2003).

4 In a collision, the matter will be heated to over a trillion degrees which is more than a billion times the temperature of the sun. If quark-gluon plasma is formed in a RHIC collision, it will last less than 10^{-22} seconds and due to the small size, the impact would not be larger than the impact of two mosquitoes colliding (BNL 2004).

5 In one of the first studies that contributed to the development of ANT, John Law (1986b) had identified two possibilities for establishing long-distance control. These correspond to the first two ways of communication just mentioned: ‘inscriptions’ and ‘drilled bodies.’ Later on, actor-network based works concentrated on the role of inscriptions for network-building rather than examining both phenomena with the same intensity.

6 Latour developed his concept of circulating reference by following earth scientists into the field. His example for such a transformation from matter to form refers to a pedologist who removes a clod from a sample in order to put it into a pedocomparator, where it represents a certain location and depth of the soil in question (Latour 1999b: 49f).

7 This point first came up in discussions with Mike Heffernan. I am also grateful to Steven Shapin for emphasising this implication after the presentation of a different version of this paper at the Second International Symposium on Knowledge and Space in Heidelberg (September 2002).

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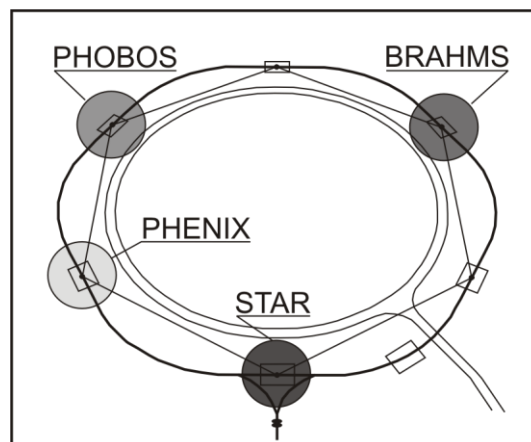
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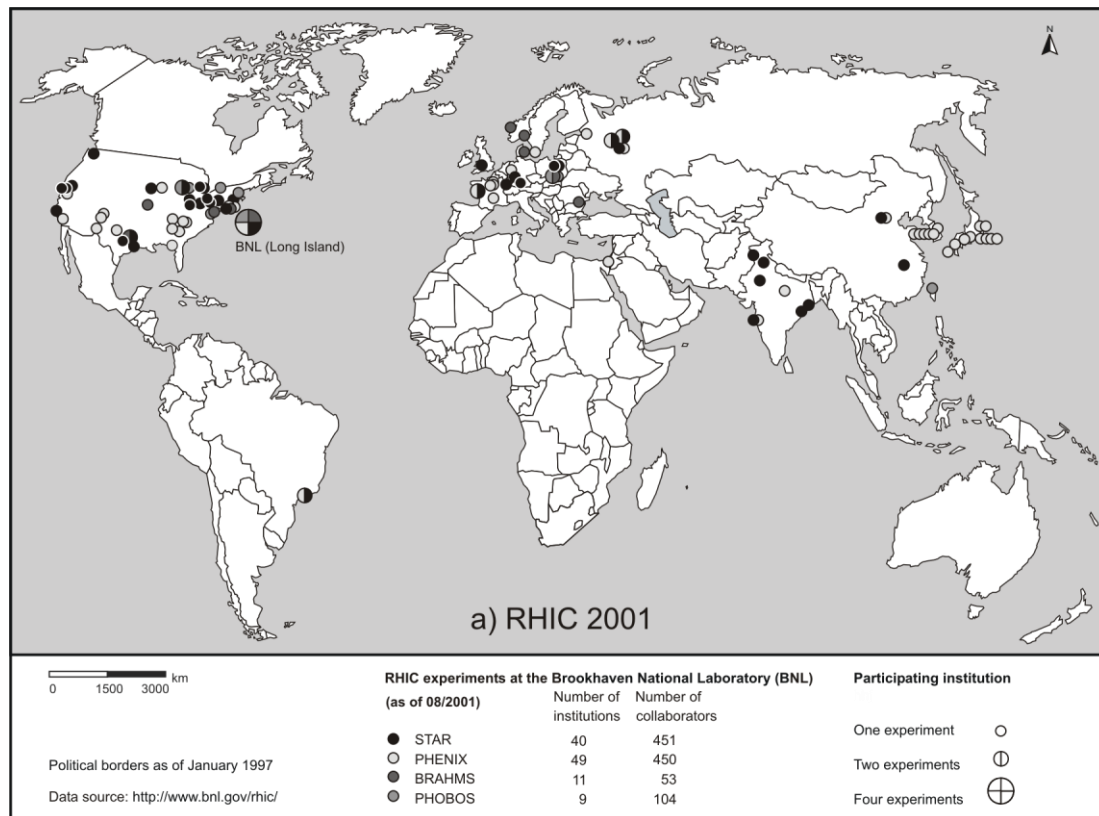
Figure 1 Location of the detectors operating at the
Relativistic Heavy Ion Collider (RHIC).



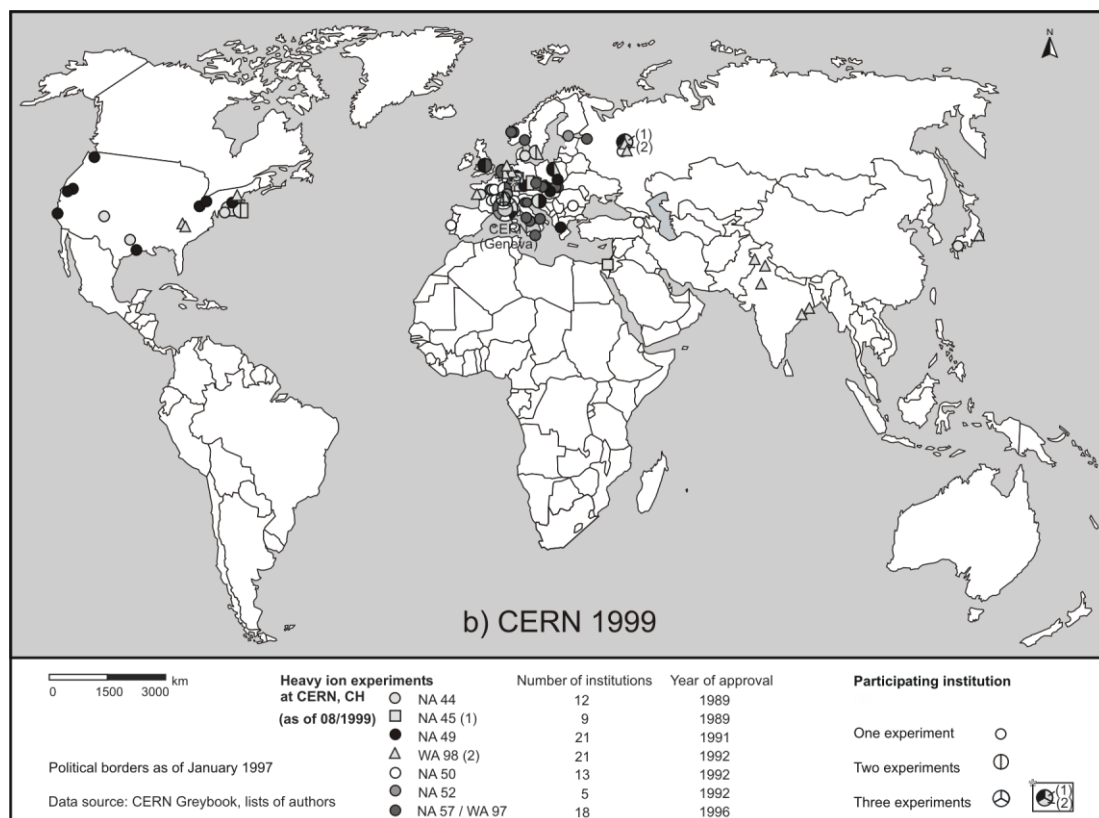
Source: BNL 2004, redrawn.

Figure 2 Participating institutions in high energy experiments

a) RHIC 2001



b) CERN 1999



Data source: a) BNL 2001, b) CERN Greybook, lists of authors.

Figure 3 The symmetry of actants according to Latour (1999b). Author's design.

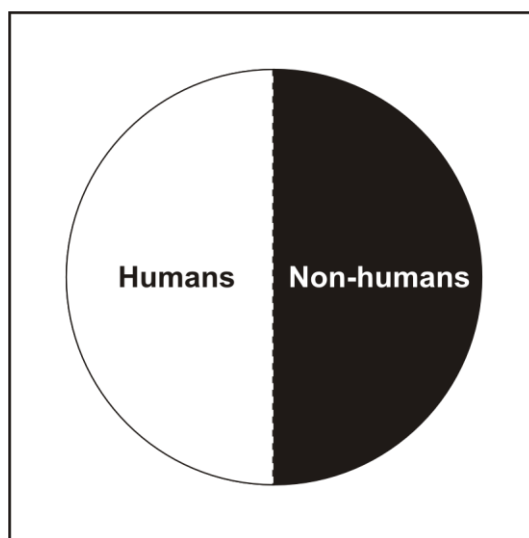


Figure 4 The asymmetry of actants implied in Latour (1999b). Author's design.

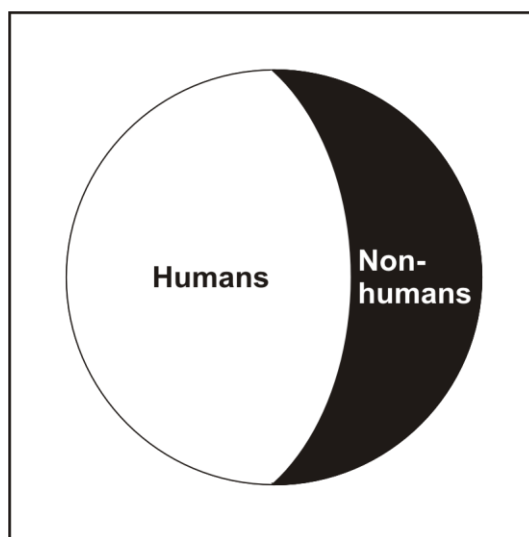


Figure 5 a) Latour's concept of 'circulating reference.' Source: Latour 1999b: 71-73, redrawn and supplemented. b) Chains of transformation in RHIC experiments. Author's design.

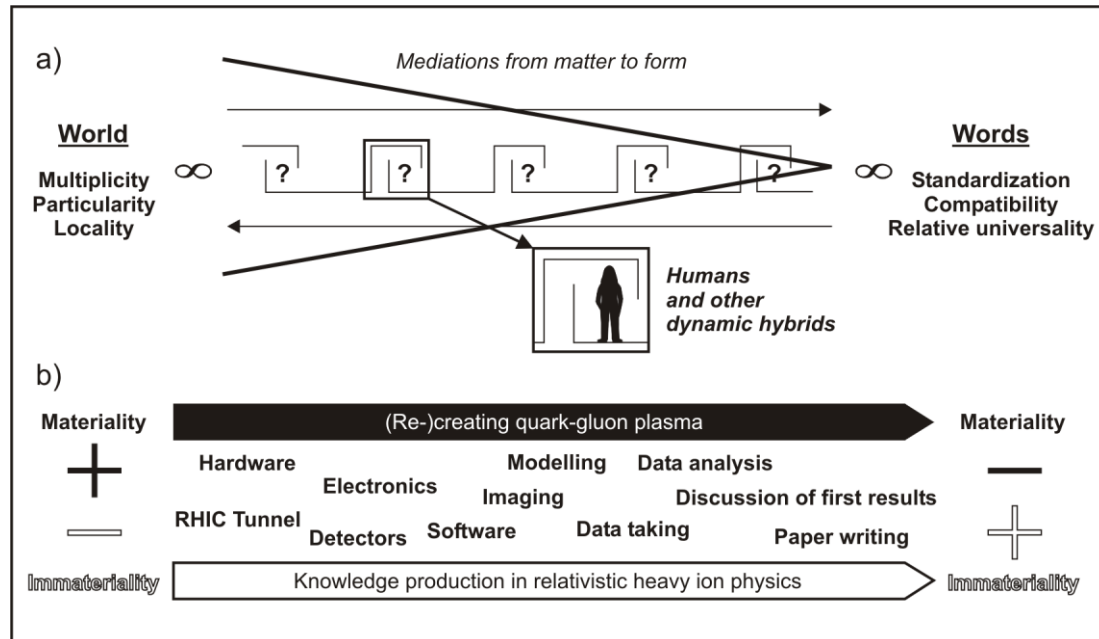


Figure 6 Humans as dynamic hybrids. Author's design.

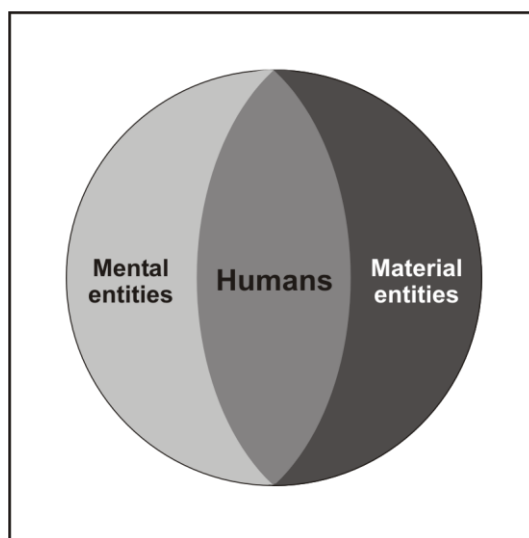


Figure 7 A complex trinity of actants. Author's design.

