Heterogeneous Engineering and Tinkering[1]

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Introduction: Utopia or Tinkering?

Thank you for your kind invitation to address your conference today. It is with particular pleasure that I do so.

At a moment when we are faced with so many global problems – natural, environmental, financial, military, social and technological – it is particularly appropriate that we explore the origins of some of these and ask how natural science, social science and the arts might be able to help us address at least parts of those problems. For this much is clear. Many of the issues that we face have been brought upon us as a result of *human* activity. Even a tsunami – certainly not the work of human beings – has consequences that are vastly exacerbated by decisions about technologies such as nuclear power stations and where to locate them. And then, another example, it is clear that famine is almost always, in part, a result of human activity or inactivity. Sadly this is obvious in the current state of emergency in the Horn of Africa. So I start by welcoming the challenge that you set. The question is: how might we address the difficult state that we are in?

I also admire the committed optimism of the conference organisers. The title to which we speak, 'The Body and Catastrophe: Towards a New Utopia' both holds out hope, and suggests the need to tackle our topic broadly. So, for instance, the conference perspective on the body is wide. In this way of thinking the body is a set of *sensibilities*, the body is a *community*, the body is a political and social *collectivity*, and the body is also writ large across the face of the *cosmos*. And this is right. If we are to think about bodies, then it is important to think about them metaphorically as well as literally.

So all this is to be welcomed: a broad approach, together with the optimism that goes with this. At the same time I want to start by thinking carefully about the idea of *utopia*. So let me briefly say why.

There is a large academic literature on the character of utopias, and there have been many versions of utopia in modern Western history. You will know this, but the term 'utopia' came into English in the writing of Englishman Sir Thomas More in 1516. The word is derived from ancient Greek, and it has a double meaning: *ou-topos*, meaning a non-place, *no* place, that is, a place that does not exist; and *eu-topos*, a *good* place. So in his book, *Utopia*,[2] More wrote, albeit ironically, about a non-place, an imaginary place that was also a good place. In the way he conceived it, this was an imaginary island with no private property, orderly social arrangements, and complete religious tolerance – except for atheists. Like all of us, More was a creature of his time and place. He was strongly influenced by the optimism of the European Renaissance, and he was also a deeply pious Roman Catholic: indeed he was later to lose his life for his religious beliefs.

But what's important here is that term, *utopia*. Because More was the first of many in the traditions of Western thought who wrote fiction about a *better* world that was also an *imaginary* world. So there have been religious utopias, there have been political utopias, and there have been social utopias. But always the idea has been that human kind would be able to perfect itself – would be able perfect its social body – if only it could work towards utopia.

But *which* utopia? Of course we can debate this, and the modern Europeans did. Because it also turned out that what was good from one point of view might be thoroughly nasty from another. I am not sure that Marxism or Fascism count as utopias, but they were (or are) schemes for creating supposedly better social orders. And – I guess we do not need to debate this – when people started to rule in their name, very unpleasant consequences quite often followed including genocide, famine, and world war, to name just three. The kulaks or the Jews, the people who didn't fit, were killed.

So, here's the problem, one person's vision of the perfect world is another person's idea of total disaster. Or, to put it differently, on the one hand there are *utopias*, and on the other hand there are *dystopias*, a dystopia being an imaginary place that is also a bad place. And indeed there are many literary explorations of dystopias, my favourites being

[2] More (1992)

Animal Farm and *1984*, by the English twentieth century socialist writer, George Orwell[3]. The first of these works, *Animal Farm* is a satire of Stalinist communism. The animals throw the cruel farmer out and take over the farm. But then, and little by little, hierarchy creeps back in, the pigs turn into the bosses, and a new slogan emerges. It is no longer 'all animals are equal'. Instead it becomes 'All animals are equal, but some animals are more equal than others.'

So this is why I am cautious about the notion of utopia. Good schemes, even good schemes implemented by good people, have a nasty habit of going wrong. Or, to put it in a different way, the world has a nasty habit of being more complicated than is imagined by those who seek to put it right. It has a nasty habit of escaping our schemes to make it better. It even has a nasty habit of biting back at us. Just when we think we have got something that is beneficial working properly, we discover that it is all going wrong.[4]

And it is this rather cautious approach that underpins my contribution to our conference. I can, of course, think of all sorts of worlds that might be better than the one we actually live in. But I am also scared of large-scale promises of better worlds and how they might be achieved. I tend to think, as I have just been saying, that these will go wrong. And I am also pretty sure that what looks good will also turn out to have difficult – even catastrophic – unintended consequences. Nuclear power in Japan appears to be a case in point. The extensive use of fossil fuels and the knock-on effects in the form of climate change is an obvious second. An intensive, protein-based, world agricultural system that feeds many of us very well, seems to be a third because, in complicated ways, it contributes both to obesity in the rich parts of the world, *and* to malnutrition elsewhere.[5]

We can debate the specificities, but this is why I prefer to think about catastrophes in a practical and down to earth way. It is also why large

[3] Orwell (2000a; 2000b).

[4] Scott (1998)

[5] Lang and Heasman (2004)

schemes to put catastrophes right worry me. Though there are no general rules, when I start thinking about these issues I tend to want to propose that we should work on a small scale. I tend to want to propose that we *experiment*. And, to use a metaphor explored by Annemarie Mol in this conference and in other writing, I want to work by *tinkering*.[6]

Heterogeneities and Flows

So how to think about disasters in this modest and practical way?

This is where I want to make my second suggestion, and it is this. We need a way of working in which we are able to think *simultaneously* about three things that we normally tend to keep in separate boxes. We need to find a way of thinking about the *social*, the *technological*, and the *natural*, all together. This is because though it is often convenient to distinguish between them, in the context of catastrophic collapse we usually find that they are all intertwined and that it really is impossible to separate them out.

In one way this is very obvious. Think of the Fukushima nuclear disaster.[7] The basic facts are clear. The triggering event was natural – the earthquake, followed fifty minutes later by the tsunami. The reactors shut down during the earthquake, as they were designed to do. And electricity to the site was also cut off. But all this was predictable. There was backup power, first from diesel generators, and second from batteries. This power was needed to keep the cooling systems running. But, as you know the tsunami breached the sea defences and flooded the basements of the turbine buildings. Where were the generators located? The answer is: in the flooded basements of the turbine buildings. So the diesel generators died, and then, a few hours later, the batteries died too. The result was catastrophic failure. Three of the nuclear reactors melted down and the result was a Level Seven incident as measured on the International Nuclear Event Scale, an incident

[6] Mol (2008)

[7] See, for instance, Perrow (2011); von Hippel (2011); Nöggerath (2011).

causing serious health and environmental damage as a result of widespread radiation contamination[8]. Indeed a major accident.

All of this is well known, even if the details are still being debated and the final outcome is unclear as I write in November 2011. But my reason for mentioning it is that we have here an *intersection* of the natural, the technical, and the social. TEPCO, the Tokyo Electric Power Company, is, of course, a social and an economic organisation. A lot of bad things have been said about the company since March 2011, but from the point of view of my argument it doesn't really matter whether these are true or not. What's important is that it is a *social* organisation. All companies are *necessarily* social organisations, with their hierarchies, their practices, and their compromises. There is no such thing as an organisation that is not a social organisation.

All this means that if we look at a nuclear reactor, like those at Fukushima, we need to understand that we are never just looking at a building or a complex *engineering* structure. We're looking also at a *social* structure. And we are looking, too at a structure that is natural and belongs to the natural world, as well.

How to think about this? My suggestion is that whenever we start looking at a disaster we think of it as the failure of a *heterogeneous system*. And I want to call it a 'heterogeneous' system because whatever has gone wrong represents a necessarily tangled and complex network of technical relations, social relations, *and* natural relations. Indeed, and this is really my point, it doesn't help all that much to separate them out. This is because *technical* relations (say the location of the backup power generators) are *also* and at the same time social relations and *natural* relations. They are social relations because they unavoidably reflect and embed organisational decision making. And they are natural relations because they reflect and embed the natural properties of materials and their interactions.

[8] Ministry of Economy (2011)

All this is surprisingly difficult to think about well, at least in English, where we tend to think of the technical as being more or less separate from the social, and both of these as being more or less separate from nature. We know, of course, that they *interact*, but we still tend to think of them as different *kinds* of things because, somehow or other, they belong to different categories.

So this is the problem. If we are to understand disaster – or more generally complexity – then we need to find a way of thinking that articulates the fact that *all* the relations that we're looking at are simultaneously natural, social and technological. We need to think about *heterogeneity*.

Let me conclude these introductory thoughts by making a further brief point. It is tempting to think that technical decisions need a bit of added social analysis if they are to work well. It is tempting, in other words, to think that the technical has to do with a more or less well-ordered set of relations, properties and attributes which then fail because they were let down by the social in one form or another: for instance by social prejudice, organisational failings, economic constraints, or political infighting. It's tempting, then, to think of the social as being some kind of a more or less unfortunate *afterthought* that spoils – or at least might spoil – well-engineered technical relations.

I can't discuss this in detail here, but I *do* want to say that this is a misleading way of thinking about the problem. This is because – and indeed I have just been saying this – the social is always integrated *into* the technical *right from the beginning*. The technical is always partly social. (I might add, though I won't discuss this here, that this means that the social is always partly technical). There *is* no technical without the social, except in the dreams of engineers - and even *those* dreams are social!

This means that if I have a single suggestion about how we should organise our thinking about catastrophe and its prevention, then this is that the social needs to be integrated into our thinking right from the start. I am saying, then, that it is inefficient at best, and dangerous at worst, to think of the social as some kind of an addition that can be 'bolted on' after the engineering has been done. It needs to be *integrated* instead. So, for instance, why did the Fukushima designers put the emergency generators in the basements of the turbine rooms rather than the more tightly sealed reactor buildings?[9] One answer is that they were overruled by the powerful decision makers in TEPCO. And we are told that this is because the General Electric designers of the reactors stipulated, as they always did, that this is where the generators should be located. No doubt there are good reasons for this, but it is clear that in the present case there were also good reasons for *not* putting them there too. And at the time the reactors were being built TEPCO was just getting into the nuclear industry, and the decision makers were not able or willing to alter the GE plans in any way at all.

But I don't need to go into any more detail here, because my basic point is simple. What looks as if it is a technical or an architectural decision is also *social* in character. It is *both* of these things. It is *heterogeneous*. What we need, then, is not just *engineers*. For the same reason we don't just need sociologists either. What we need instead are *heterogeneous engineers*. Indeed, I suggest that this is a new profession that needs to be invented.[10]

So our problem is how to understand the sets of relations that make up *heterogeneous bodies*, how they work, and how they go wrong. If we can't immediately create a new profession we can at least look for metaphors to think about these their relations. We might, for instance, think about flows: about what flows, where it flows to, and how wrong flows, flows that might lead to catastrophe, might be prevented. To think about this, I will start with real flows, flows of water and flood engineering. Then I'll move on to some more metaphorical flows.

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[9] Yoshida (2011).

[10] For discussion of heterogeneous engineering, see Law (1987).

The US Army Corps of Engineers has been re-engineering the Mississippi and its tributaries for a century.[11] Like the Korean Four Rivers Project[12], this is engineering on a heroic scale, but so too are the reasons for doing it. First, it is intended to prevent large scale flooding. There were six major floods between 1849 and 1927 in the Mississippi basin, and it was the last of these that led to the Mississippi flood control project in its contemporary form. Second it is intended to make the river navigable. And then, third, it has released the floodplain for agriculture and settlement. Indeed, since 1940 about four fifths of the original floodplain has been drained.

All this went wrong in 2011, in 2005 and in 1993. For instance in 1993 the Mississippi rose, three billion cubic metres of water broke through the dykes and seventeen thousand square miles of the floodplain were submerged. So why did the disaster happen? Excessive rainfall was important, but critics say that flood control was also crucial. They argue that the whole idea of trying to control the flows of nature on such a large scale is flawed. They say that there will always be huge floods which are larger than allowed for in the design specifications, but add that river engineering contributes to flooding for two reasons. First, if you take away meanders by shortening channels, then you increase the river's gradient and it flows more fiercely. But the river doesn't like this and tries to return to its original state by creating new meanders. This means that engineering is constantly struggling against the river. And second, wetlands absorb water fast and release it slowly, so if you take them away rainfall gets into the river much more quickly. Flooding is more likely. The whole system is no longer self-correcting.

So we're in the business of flows here. Literal flows. We're in the business of trying to control those flows. And then we're confronted with this paradox. Control is possible, it is possible on a large scale, and there are good reasons for attempting it. But the down side is that the river bites back, the flows are liable to get out of hand, and this happens

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[11] See US Army Corps of Engineers (2003), Walker et al (1994), Larson (1996), and Johnson et al. (2003).

[12] Normile (2010)

at least partly because we try to control them in the first place. Attempts to avoid disaster are also working to generate the conditions for disaster.

So how does this story about flooding help us to think about flows in heterogeneous bodies more generally? One answer is that flows imply barriers that hold fluids in place and regulate the flows, but those barriers are risky too, for when they are breached the consequences are dangerous for the heterogeneous body. With this thought in mind, let me talk about a second catastrophe, the UK's 2001 foot and mouth epidemic.[13]

Global Flows, Barriers and Epidemics

The UK's foot and mouth story is not unlike that of Korea. The country is usually free of the disease, but occasionally it breaks out. Why? Well the standard stories vary a bit, but most of them start from the outside.[14] So, for instance, the strain the disease that came to the UK in 2001 was first identified in Central India in 1990. At first it was probably carried by the wind, by infected animals, and by direct contacts between animals. Then it was also carried along the trade routes so that by 1998 it was globally widespread, and by 2001 it had appeared in countries such as South Korea, Japan, and the UK which are usually disease free. Straight away, then, we have to think about a heterogeneous combination of natural, social, and technological flows.

But global flows imply global barriers. Why are some countries disease-free? How is the viral flood kept out? The answer is that the Organization Internationale des Épizooties maintains a list of the animal diseases statuses of different countries. For foot and mouth, countries are either disease free *without* (routine) vaccination, disease free *with* vaccination or suffer from the disease *endemically*. This classification is

[13] For large scale inquiries into the UK's foot and mouth epidemic, see Foot and Mouth Disease 2001: Lessons to be Learned Inquiry (2002); Royal Society (2002).

[14] This is a recurrent trope in discussions of infectious diseases. Note that the non-vaccination policy of the EU, which originated in the UK, is also controversial and historically specific. For discussion see Woods (2004)

used by the WTO to regulate trade relations. Countries that are disease free without routine vaccination (mostly the wealthy countries) are able to export their animals anywhere, while in most poorer countries the disease is endemic, or they vaccinate, so their trading opportunities are much more restricted. To put it differently, the OIE/WTO rules of trade act as a barrier around the privileged countries. Animals and meat products flow out but not in, while in theory viruses are kept out.

This division between inside and outside brings economic advantage for those within. First, as we have seen, trade is relatively unregulated so markets are larger and more valuable. Second, the direct costs of the disease (loss in weight and in milk production) are avoided. Third, the cost of vaccination is avoided. To create a disease-free zone is like draining wetlands and building on them. In areas such as Europe it brings benefits for producers, and probably for consumers too, but it increases the risk of viral flooding. It also induces a kind of complacency. Hydraulic engineers sometimes talk of the 'levée effect'. This is the false sense of security that grows among those who live behind dikes. It is the loss of memory of that is the downside in any contract with control. To create a zone free of foot and mouth disease leads to the levée effect. Viruses are always trying to flood in because people are keen to move animals into the disease-free zone for economic reasons – a process that gets easier with improvements in global transport. And the flow of illegal animal products is real enough and difficult to police. For instance, in 2000 around 2.5 million containers arrived in the UK, and perhaps 100,000 were inspected.

In the UK foot and mouth was discovered on 19th February 2001 at an abattoir in the south of England. Some pigs were unwell. But where had the virus come from? Thousands of animals had come to the abattoir from 600 farms, so inspectors visited those farms and three days later they discovered massive infection on a farm in the north of England. But had it got there? Painstakingly, the vets worked through a whole series of possibilities, and then they looked at the feed, for the pigs had been fed catering waste from bakeries, hotels, restaurants, schools and a military facility in the area. The law said that this had to be boiled before it was fed to the pigs, but it turned out this wasn't happening. The evidence was circumstantial but overwhelming: the pigs had been infected by unsterilised waste that had, somehow or other, included illegally imported meat.

But this was just the beginning of the epidemic. The disease had jumped to sheep on a few nearby farms, and these sheep had been taken to market where they had been mixed with 25,000 other animals and sold to 180 farms all over England and Scotland. All animal movements were stopped, but it was too late. The next day the disease was discovered in the far south of the country. And by 4th March there were sixty-seven outbreaks spread right across England and the south of Scotland.

So why had a leak turned into a flood? The reasons included the following: one, the farmers hadn't reported the disease; two, the disease is virulent in pigs and they become very infectious (so the infection spread to other farms); three, the disease is difficult to detect in sheep which meant that once they were infected it travelled without anyone seeing; four, the fact that the weather was cool and damp which was good for the virus; and five, the wide use of contract labour on farms meant that lots of people were coming and going, and spreading the infection.

So these were *heterogeneous flows*. The social, the technical and the natural were all working together. And those flows were very large. For a variety of reasons, many animals were on the move. Partly this was because there were only 411 abattoirs in the UK (down from 2000 in 1970.) This was first because the food industry in the UK is centralised and big purchasers wanted to deal with a limited number of suppliers; second, because every slaughterhouse needed a resident vet and with food scares the rules of hygiene were strict and costly; and third because sheep were moving widely anyway: from highlands to lowlands in the spring; between different national markets; and because the European Union's Common Agricultural Policy (which has since changed) paid farmers a 'headage allowance' for the number of (authorised) sheep they owned on March 1st and the farmers were making sure that they didn't have too few animals.[15] And these were the flows which, more than any other, carried the foot and mouth virus round the UK; which turned the leak into a flood which engulfed over 2000 farms and led to the killing of six and a half million animals.

The epidemic was stopped at a cost of around £8bn, but it caused grief and loss for many farmers. No one alive at the time in the UK will ever forget the pyres, while those who lived in the countryside will never forget the smell of the burning as the carcasses were incinerated. Almost no one died but in many areas people could not move from their farms. The countryside was effectively closed to visitors for many months. The tourist industry and rural economies were severely damaged. Many were hurt economically, socially, personally, and spiritually. And, more generally, the disaster led to questions: why are we doing this? Is this a good way to *live*? Do we want to create a world in which the social and animal body, individual and collective, is treated in this way?

Conclusion

The hydraulic metaphor of engineering helps us to think about complex and heterogeneous relations and flows. It reminds us that these are precarious, that the barriers behind which we shelter may work but they are also vulnerable. But of course we are not dealing not with a single flow, the flow of a virus but with a web of partially connected and different flows and barriers: animals; trade; economics; personal movements; policy regimes; safety and hygiene systems; and the viruses themselves. All of these flow. All imply barriers. And all of them, their intersections and the intersections between their barriers, play their part. This is a *heterogeneous system*, a body of relations that works a lot of the time. But sometimes it does not. So the question is: do we want to create our heterogeneous systems – our heterogeneous bodies – in this image?

[15] This was one of the most important reasons for the massive movement of sheep. In 2001 perhaps *two million* were traded in January and February, in part because farmers were topping up their quotas.

I've said that I believe we need to think outside the disciplinary boxes. If the flows are heterogeneous, then we need to think in ways that can handle that heterogeneity. We need to be able to recognise that we are dealing simultaneously with the natural, the technical and the social. And I have said that this is quite difficult. But let me conclude by talking briefly about one way of thinking about this that I find very helpful. It comes from the writing of sociologist Charles Perrow[16].

Perrow is concerned with sociotechnical arrangements such as chemical plants, air traffic control systems, and especially nuclear power stations. His argument is about the architecture of vulnerability and is disturbingly simple. Imagine, he says, two features of complex systems. Think first of *coupling*. Some systems, he writes, are *tightly coupled*. This means that the flows in them are rapid – or at least too fast for us to intervene. Then there are *loosely coupled* systems which flow slowly. These are relations where we can intervene if things start to go wrong. So coupling is the first feature of systems. And the second has to do with *complexity*. In complex systems the flows ramify off in all sorts of directions. There are many connections and side-channels. Then others are *linear*, not complex. Here flows are relatively straightforward. They move downstream in one direction.

Then Perrow makes the following crucial observation. When things go wrong in systems in which flows are *both* quick *and* complex the consequences are unpredictable and difficult to control. They overflow and spread. The result is collapse. The classic case is the nuclear power station. I've already mentioned Fukushima, but Perrow writes much more extensively about the Three Mile Island nuclear accident in the US in 1979. As I said, his argument is very simple. In a nuclear reactor, when something goes wrong it goes wrong quickly (the system is tightly coupled), and ramifies unpredictably through the system (because it is complex, not linear). There is a high risk that such turbulent flows will break through the barriers that are supposed to keep them in place – and the result will be collapse.

[16] Perrow (1999)

Then Perrow talks about the level of hazard. If collapse isn't dangerous then it doesn't matter. We can live with it. But if collapse is dangerous then, he says, we need to take a political decision not to create such systems in the first place. This is his view of nuclear power – and he has repeated it in the context of the Fukushima disaster[17]. Because nuclear reactors are tightly coupled and complex, it is only a matter of time before something will go wrong with catastrophic consequences.

Some disagree with Perrow. They argue that a culture of safety can overcome the intrinsic dangers of systems that are tightly coupled and complex. They point to commercial aircraft which mostly operate safely in developed countries, and to air traffic control systems[18]. No doubt they are right in part, but I am not entirely persuaded. In a complex system with rapid flows, what Perrow called 'normal accidents' are always out there, waiting to happen. They happen, this is the point, *unpredictably*. And it is also likely that some people in a complex system won't be so worried about a culture of safety anyway: certainly the farmers where the foot and mouth disaster started in the UK were not particularly committed to a culture of safety.

Where, then, does all this leave us? How might we think about the heterogeneous relations that make up the social body? How might we think about their potential for catastrophe? There are many possibilities, but I have tried to suggest that Perrow's analysis is a useful tool for thinking about flows, barriers and vulnerabilities.

The successes of nuclear power and the absence of foot and mouth most of the time in countries such as Korea suggest that control is possible. But only precariously. The complexities of the intersections in these regimes of flow and, the inevitable limits to a global culture of safety, suggest that we are vulnerable. They suggest, for instance, that global agriculture is a set of accidents waiting to happen. As night follows day, there *will* be bad farmers, and there *will* be uncontrolled imports. Or faulty design decisions, or sleepy operators in the case of nuclear power.

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[17] Perrow (2011)

[18] See, for instance, Roberts (1989).

In which case there is no point in getting angry about *individual* delinquencies. Instead would be wiser to think about a global body and global relations that are *less* prone to breakdown. That are *less* dependent on such leaky barriers. Arrangements that depend *less* upon surveillance and the need for centred visibility. Heterogeneous bodies, in short that are *less* vulnerable.

I started by saying that I believe we need to be cautious about utopian hopes. It would be better, instead, to find ways of tinkering towards reliability and sustainability. To do this we need vocabularies for thinking about and describing the heterogeneity of the flows and relations that make up the social body. And we need non-disciplinary ways of thinking about those flows and the ways in which they behave. And that is the message that I want to leave you with. If we are to build a better and a safer world, we need to attend to it in its specificities. We need to be able to talk engineering and sociology and science and economics all at the same time, and more or less case by case. And we need to understand that our devices and desires necessarily have their dark side too. That the world will bite back.

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