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THE RIGHT INFORMATION IN THE RIGHT PLACE AT THE RIGHT TIME: PRECISION AND MULTIPLICITY IN MEDICAL PRACTICES

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Abstract

Does the quest for 'the right information in the right place at the right time' create a blind spot in development and implementation of ICT support for complex work practices by spurring wild-goose-chases for 'the one, right representation'? Could resources be spent more fruitfully by shifting focus towards the multiplicities of information practices in such settings, and how to support rather than attempting to obliterate them? Based on the study of a hospital ICT implementation, this paper challenges the notion of a singular and linear precision. Illustrated by the measuring and (re)presentation of blood pressure, precision emerges as a multiplicity, enacted in different socio-material practices; blood pressure is not only a function of how it is produced, but also of the diverse purposes it serves. It is argued that this should have implications for how we think about information and its representations in all phases of the system lifecycle.

Keywords: Precision, multiplicity, healthcare information systems, medical practices.

1 Introduction

What is precision? Or more precisely; what is a precise information system? Google Scholar lists a total of thirty contributions applying the concept, of which none actually defines it. Assuming a common sense understanding as sufficient is undermined by "*The values of precision*" (Wise 1995), where an entire anthology is dedicated to the exploration of precision. In the end, the authors are not able to agree on a single definition, or even on the difference between precision and accuracy. But we do get this: "*Precision is everything that ambiguity, uncertainty, messiness, and unreliability are not. It is responsible, nonemotional, objective, and scientific. It shows quality*" (Wise 1995a, p. 3).

The close relationship between precision and technology – where faith in one normally rests on faith in the other – itself justifies a closer look into what precision might mean in this context. In relation to information systems, "the right information in the right place at the right time" has been a popular slogan for a long time. Is this precision? If so, is precision then a question of finding the one, right representation for all purposes? Or is it about differentiating information needs in different contexts at different points in time for different purposes? Questions like this have (or should have) implications for the design, implementation and use of information systems, as decisions and actions taken (or not taken) here together determine what information is available, where and when. Nevertheless, precision in relation to these passages of the information system lifecycle is rarely explicitly problematized as such. In this contribution precision is conceptualized as an aggregate accomplishment of complex socio-material networks, heavily influenced by their historicity and purpose(s).

Precision is an implicit and most often taken for granted – yet not unproblematic – feature or attribute of all technology involved in the production and use of information and knowledge. The right information in the right place at the right time is what information technologies are normally expected to deliver, illustrating how this goes for qualitative and quantitative precision alike. In daily decision making practices (whether it is about how much to charge for a kilo of tomatoes or how to care for an emergency room patient) we would all like to have access to the information we need, when and where we need it. And when our organizations introduce new information systems in order to provide us with this, we subsequently expect these systems to deliver the precision we need to make confident (and hopefully good) decisions. Within the health informatics literature, IT is perceived as the solution to major problems of quality and cost in public health care by providing the right information in the right place at the right time (Hasman 1998; Humber 2004): *"Having the right information in the right place in the right time is a prerequisite for the delivery of safe and effective care"* (Stedman 2010, p. 37). Some take a fairly positivistic approach to this, foregrounding uniform solutions and precise definitions as chief concerns (Winter et al. 1996). This resonates well with the technical focus within current software development practices, where defining accurate representations is a core activity. Others are more sensitive to the problem of predefining the right information, the right place and the right time; emphasizing the importance of users' experience and contextual understanding (Cegarra-Navarro & Sánchez-Polo 2010). Still, little attention is paid to what might constitute the right information in the right place at the right time, and even less to the possibility of generalizing this question (and its answers) beyond single local contexts. Is there really such a thing as the right information in the right place at the right time? And if there is, what do we know about it? How do we distinguish it from that which is *not* the right information in the right place at the right time?

Within medical care, blood pressure has been a vital parameter since the dawn of modern medicine. While measuring blood pressure by palpitation stretches all the way back to ancient China and Egypt, the rise and "scientification" of European medicine during the 18th and 19th century was followed by the introduction of instrumented measuring methods that also raised precision as a relevant concept. Thus medical technology entered as a significant actor in the production of what was anticipated to be a more precise information system. Since then the discussion has been on about how precision should be produced in this context – a discussion that is equally relevant today with the introduction of a new breed of technologies in the clinic; the electronic medical chart (emc) systems. The case of blood

pressure measuring is thus apt for investigating the concept of information system precision for the purpose of providing the right information in the right place at the right time.

This contribution describes the implementation of an emc system (hereafter simply referred to as the EMC) in a major Norwegian hospital, and shows how precision in relation to blood pressure measuring is not simply *provided* by the technology, but rather *co-produced* and subsequently *reproduced* in a complex socio-material network. It further illustrates how blood pressure is not only a function of the way it is measured, but also of the purpose for which it is used in different contexts at different times. Based on this, the notion of a singular and linear precision is challenged, suggesting the co-existence of multiple precisions that all must be accounted for by the network. When generalized, this has implications for the design, implementation and use of information systems, where precision traditionally has been regarded merely an issue of finding "the one right representation". If the "precision multiple" accounts for why this has proven so difficult, resources may be reallocated for investigations into how such a multiplicity can be supported rather than (sought) eliminated.

2 Precision, blood pressure and the dawn of a science

Precision emerged as a significant concept along with the scientification of western societies in the late 18th century (Wise 1995a). Under this influence, the instrumentation of blood pressure measurements entered the medical laboratories. The precision associated with instruments such as the sphygmomanometer was perceived as crucial to "*a long-term vision of medicine becoming more of a science and less of an art*" (Moreira 2006, p. 72). Carl Ludwig, the inventor of the kymograph (the part of the sphygmomanometer that produced the graphical representation), is frequently referred to as the founder of modern physiology (Bauereisen 1962; Holmes & Olesko 1995). The introduction of new technologies like the sphygmomanometer made it possible to measure with precision in ways that supported both quantification and elimination of subjectivity (Borell 1987). However, it would take several years before the production of this precision was considered secure enough to enter the clinic (Booth 1977; Naqvi & Blaufox 1998), and even longer before it was commonly considered precise enough to justify its application on a regular basis. The following citation from a 1904 book on the topic is illustrative of this process:

"*The modern physician's armamentarium is so complex that additions to it are far from an unmixed boon. Nevertheless, the sphygmomanometer has been welcomed in many quarters as an instrument of real value. Two questions, however, must be fairly and squarely answered, before its general use can be advocated; First, Does it yield accurate information, which can be had in no easier way? Second, Is this information worth the extra time expended in obtaining it?"* (Janeway 1904, p. vii).

Today, safety in clinical operations depends on this precision, produced and made available through the medical charts: "*We can't manage for five minutes without the medical charts. Then the patient would be dead – many would die if we didn't have this information. So this is essential – that it works*" (ICU nurse). However – as we will see – Bruner's (1978) claim that blood pressure is a function of the way it is measured is still valid. And there are still multiple ways to measure blood pressure.

Drawing on Mol's (2002) conceptualization of disease as a multiplicity, enacted in different socio-material practices, Moreira (2006) suggests that different ways of measuring blood pressure constitutes a mutual parasitism; a concept that aims to capture the dynamic and mutually exploitative aspect of collaborating knowledge practices. This foregrounds the "multiple doings of 'the same' object" (p. 80), and thus establishes 'the blood pressure multiple'. But the singular conceptualization of precision is maintained as a linear scale ranging from 'low' to 'high' and used to distinguish the different methods in relation to the notion of an 'actual blood pressure'. This singularity can be challenged.

Like blood pressure, the precision of its representations is consequently also a function of the way it is measured. But precision is a function of its purpose as well; what is perceived as ambiguous,

uncertain, messy, and unreliable to some might be perceived as responsible, nonemotional, objective, and scientific to others. And what is perceived as responsible, nonemotional, objective, and scientific in one context might be perceived by the same people in another context or at a later point in time as ambiguous, uncertain, messy, and unreliable. Precision is always a product of, and thus judged according to, its purpose, and that purpose varies over space and time (Olesko 1995; Holmes & Olesko 1995).

Somewhat counter intuitive, this illustrates how precision is not a particularly precise term. Precision points to different (but related) attributes of a representation – such as accuracy, resolution, granularity and reliability (Wise 1995a). But even in communities where agreement is more or less established regarding the meaning of the term, there can still be considerable variation in regards of what represents precision, as well as what precision represents. How do you tell a precise representation from one that is not? While precision is about making distinctions, this particular distinction is not always self evident. If unable to make it, we might be forced to acknowledge the existence of a 'precision multiple' as well; enacted in the socio-material practices where it continuously is not only produced, but also take part in reproducing itself. Precision is always the accomplishment of networks that also includes material and other artefacts (Wise 1995a). The production of precision is performed in hybrid colletifs (Callon & Law 1995), through "*a chain of small re-representational tasks being performed by a series of heterogeneous entities*" (Berg 1997, p. 145). In this process of circulating references (Latour 1999), precision concerns a lot more than just the number of decimals in the representations produced, and only on aggregate level does precision or accuracy represent meaningful notions (Berg 1997). In relation to blood pressure, the visualizations made possible by Ludwig's kymograph became (and still is) an important party in this, as:

"*the specialized information with which scientists [and anon clinicians] become deeply familiar extends the meaning of* observation *for them far beyond what can be perceived directly by the eye.* […] *This transformation can take place with special ease when it involves the spatial representation of temporal processes, because the ordinary language with which we describe the passage of time is embedded in spatial metaphors*" (Holmes & Olesko 1995, p.218).

This spatial representation of the temporal is exactly what the paper based medical charts offers to the clinicians. It is also what a new generation of ICT tools is currently trying to replace with electronic representations.

Precision is thus obviously a technical and technological phenomenon, and it can hardly be contested that it constitutes a cultural, historical and social phenomenon as well. But precision is also a practical and situated phenomenon; as the Oxford English Dictionary's definition[1] points out, precision is an act or an action, and actions are always situated (Suchman 1987). Upon reading Moreira's (2006) contribution on the production of blood pressure in neuro surgery I was convinced by his construction of a 'blood pressure multiple', but at the same time I missed a similar elaboration of *precision* as a clinical concept. Motivated by what I perceived as possible indications of a 'precision multiple' in my own material, I wanted to explore this issue further. Precision in blood pressure measurement is the outcome of multiple practices where it is enacted for multiple purposes. The socio-material composition of these practices, highly entangled with its purpose as well as with local perceptions and conceptualizations of precision, is of significant consequence to the production of precision as well as to which precision that is produced. The singular notion of a linear scale can thus be replaced by a richer understanding that acknowledges and serves justice to the multiplicity of its production.

[1] **Precision**: The action or an act of separating or cutting off, esp. the mental separation of one fact or idea from another; abstraction, definition [http://www.oed.com/view/Entry/149667. Accessed 070710].

3 Background and methodology

In 2004 the Norwegian national hospital decided to replace the paper based medical charts with a computerized solution. As a hospital wide implementation, this was supposed to serve multiple strategic purposes:

- Complete the overall strategic vision of a "digital hospital"
- Provide a uniform interface for all clinicians in the hospital for vital signs and medication
- Support "continuum of patient care" across the hospital
- Force the standardization of clinical practices, especially in relation to medication
- Accumulate documentation for both clinical, research and legal purposes

Moving from strategic to operational level, this multiplicity multiplied, as the solution would have to integrate with a large variety of clinical practices, organizational units, professions and medical disciplines. Replacing the six different paper charts in use with a single interface for all clinicians in a way that would enable de-(or rather re-)contextualized reuse of information across the hospital thus meant that this solution would have to serve a wide range of different local purposes as well. This included participation in the various ways blood pressure was being produced and used in different contexts, maintaining (at least) the level of precision already provided by existing solutions. Achieving this would prove to be more challenging than initially anticipated by the members of the project group.

The fieldwork from which the data presented here is derived started ultimo 2007, and is still ongoing. Primary sources of information include interviews with members of the project group, clinicians directly involved in or influenced by the project as well as other (more or less peripheral) stakeholders. Fifteen semi structured interviews have been conducted; all recorded and transcribed. A second source of information has been field notes from participant observation in project group meetings as well as in the clinic. Ten such sessions have been conducted, most of them in relation to project group activities. A third source of information has been relevant documents and correspondence, including the project's requirements specification, the internal evaluation of the pilot as well as strategic documents from different levels.

My exploration of the multiplicities related to blood pressure precision started by recoding this material, looking for references to blood pressure. The first thing that stood out was how pretty much all the participants used either blood pressure or medication when they wanted to illustrate something in relation to the new system. This was to me a confirmation of the significance of blood pressure as a core clinical phenomenon. Next, these findings were coded into several sub categories; automation, use, context, measuring, precision/reliability, professional discretion and standardization. These categories were selected upon repeated read throughs of the initial results. This phase of my data analysis thus resembled a grounded approach. This is confirmed by the fact that I hardly found any references to blood pressure in my field notes from the first iteration of my data collection, while the interview transcriptions from the second iteration was packed with it. I was not looking for blood pressure at that time, but it seems like blood pressure was looking for me. In order to illustrate this I have in the following section chosen to present extensive excerpts of my material. This approach (however unconventional) has the additional benefit of allowing my readers to make up their own opinion on how the data might be interpreted.

My next step was searching existing literature for relevant contributions on precision. The most important finding from this search was "The values of precision" (Wise 1995), an anthology tracing the socio-material co-construction of precision from the mid 18th century until present time. Emphasis is on the complex relations between science and precision, and the material, dialectic, semiotic and often pragmatic nature of their mutual constituency. The relations between precision, accuracy and reliability are thematized; not providing too many uniform answers, but vividly illustrating the multiplicity involved in unwrapping and interpreting such relations. In this search for the historicity of the phenomenon, Janeway's (1904) book also became an invaluable resource, as a contemporary account capturing the current discourse in real time rather than hind sight.

4 Precision and the electronic medical charts project

As digital representations of individual measurements were already available through the existing medical technical units (MTUs), decisions influencing precision were limited to how and when to record the samples in the new system, and under what labels they should be recorded. The latter might seem fairly straight forward, but the following excerpt from an interview with an ICU nurse in the thorax surgical department fairly well sums up the different aspects of how and why it was not:

Nurse: *One of the problems they* [the project group] *faced was the linguistics. In regular hospital language we are pretty sloppy. One and the same word can mean different things, depending on context. That works fine, as long as all parties understand what it is about. But when this is on a PC, it has to be clear and unambiguous terms that can be understood by everyone; those that enter the information and those that read it. This was one of the problems the EMC group faced – they saw that we used different terms... or we used the same term about several things. And then they had to paraphrase this somehow, so that you could know whether to chose A or B when clicking into EMC. The result was that words and expressions used by EMC had no historical root in hospital use. They were not incorporated, well established words and expressions. They had to create their own... EMC language. That made us wonder – indeed, what is this? So we clicked on some words, and found a word, and then – yes, this must be what they had meant. So we clicked on that and chose that. Then someone else entered the system to do essentially the same, but clicked on a different list and found a different word, and thought that – this must be it. So they would click on that. The result was that what was intended to be the same message ended up as different words and expressions. This is a huge task – to clarify... it is very disciplining – going through such a process – it forces you to become aware of a lot of things that we in everyday speech simply take for granted. And then things aren't really that simple, when it all boils down – when this is to be translated into PC language. One thing is to find a good, suitable expression, and translate some of these English words and expressions the system is based on. Then you must make the users appreciate the nuances of these new words and expressions. That's a time consuming process – it is difficult, a very difficult process, this linguistic challenge. That should not be under estimated.*

Me: *What makes it so difficult?*

Nurse: *It's that... on a PC you need clear and unambiguous terms, but we do very well without that in everyday speech.*

Me: *Why is this not a problem in the EPR* [electronic patient record]*?*

Nurse: *Because that is based on free text. Only the sections and headings are given there. So you write whatever you want.*

The problem of precisely naming the parameters for which the system should collect data was related to the structured nature of the database. As the nurse points out, this was not a problem in relation to the electronic patient record (EPR), where entries are made in free text. A structured database is conceptually based on precise and restrictive representations, while free text is by default multi-purpose and flexible. This problem escalates when the system is intended to take part in a variety of clinical practices in multiple contexts:

Me: *Does it amplify the problem that this is supposed to be hospital wide?*

Nurse: *Yes, defi... yes, I would... it would be naïve to believe anything else. For every new department you get to, you will discover nuances you were not aware of, yes. This is something I, as a user, first became aware of when I should use the system. It is one thing to read through such grand lists that has been made – it looks good then. But when I was forced, in the concrete situation, to make decisions – what should I choose then? That's when I realized how sloppy I normally am. Both in my written and in my oral language.*

Me: *Some might call it pragmatic?*

Nurse: *Or pragmatic, yes.* [Laughs]

Me: *Are the differences between units and departments about professional disagreements, or is it simply about coincidence and different traditions?*

Nurse: *The latter.*

Me: *So there would not necessarily be any opposition against shared terms, as long as they are understandable to everyone?*

Nurse: *Well... you would probably bump into that too...*

Me: *If you here at thorax ICU could have your own parameters, in line with your own terminology, would that resolve...*

Nurse: *But we were not agreeing...*

Me: *Internally?*

Nurse: *No, absolutely not. The EMC people spent a lot of time on discussing this with us, and they said that this was really difficult, because they would talk to one person and get one answer – then they would talk to another person and get another answer. So they would only be able to please one person at a time.* [Laughs]

Me: *How could these kinds of issues be handled?*

Nurse: *It requires... well, it is a decision that has to be made. A decision* must *be made in the end. And... this thing about... having control of the terminology, that is... that is power. It's about power. It's about the power to enforce your ideas, but it is also about power in how to use... Language is power – also in relation to EMC. So... language can, I believe I can... in line with Marx, say that it can alienate people.*

The above passage shows how a more precise terminology became a prerequisite for the production of precision in blood pressure measuring with the new system. As pointed out, this need for a precise terminology arised from the structured nature of the information in EMC. While the electronic patient record was based on free text entries, all information recorded in EMC had to adhere to predefined categories and formats. The problem of establishing this precision was a consequence of its intended universality in the sense of producing a single representation for all purposes across the hospital. The diversity this faced was a result of different historical reasons; pragmatic and practical, professional and disciplinary, political and even incidental.

How and when to record samples from the MTUs also proved to be a more problematic issue than initially anticipated, as illustrated by the next excerpt:

Nurse: *The arterial catheter is used as a tap – then we don't have to prick the patient every time we need to draw a blood sample. In the central venous catheter (CVC) we give medications – all temporary medication is given in the CVC, where the central venous pressure is registered as well. So all the antibiotics – the patients get that routinely three times a day; some get two different antibiotics, and then it might be six times a day – all intravenous medication, such as diuretics and cardiac medications, are given at the CVC, cause then it will mix with a lot of blood right before it enters the right heart chamber. So this is a very good way to do it. But it makes the blood pressure on the scope jump in the attic, but we don't care about that. But EMC cared about that; it was registered. So there were tremendous amounts of strange information. And we do whatever we can to mobilize the patients – get them up in a sitting position in the bed – up and stand on the floor. To do that, we have to disconnect the cables from the scope, and then the patient's pressure drops to zero. The only thing we could use EMC for then was to see how many minutes the patients had been sitting at the edge of the bed or standing next to it. But that produced a lot of erroneous measurements as well, because the patient's physical activity influenced this. And we tilt the patient up and down – the torso – and should be measured according to how the right atrium is positioned. So when a short nurse comes and lowers*

the bed, the patient's blood pressure drops unless you immediately move the hemopod that is supposed to be positioned at the same altitude as the heart. Then a tall nurse comes along, who wants to raise the bed. We don't move the hemopod every time. It is not necessary to monitor the patient. But the number of bogus measurements of the blood pressure becomes phenomenally large.

The new system should automatically harvest data from medical equipment, thus relieving the nurses from manually filling the paper chart. It turned out, however, that this involved more than simply transferring data from the equipment to the medical chart; it required professional discretion and knowledge of contextual factors. Blood pressure is measured in catheters also used to draw blood samples or give intra-venous fluids. As fluids must be infused with a pressure exceeding the patient's blood pressure, this has a direct effect on blood pressure measurements at the catheter. When manually registering pressures, the nurse would therefore first stop the infusion, wait for a few minutes for the pressure to settle; then read the value, before starting the infusion again. EMC, however, harvested these values continuously, regardless of any external influences. Thus most values recorded in EMC were erroneous. The nurse could choose to leave the chart with a majority of faulty entries, or to manually delete all but the samples where the infusion was turned off. Doing this, however, was a lot more time consuming than manually recording the information as it had to be done for three different parameters; systolic blood pressure, mid blood pressure and diastolic blood pressure.

Precision in the final representation of blood pressure thus became reduced for the ICU nurse after the introduction of EMC, as it no longer would provide an accurate and reliable indication of the patient's condition and the way in which it was evolving. For other purposes, however, precision increased. The head of the anaesthesia section exemplifies this in the following excerpt:

Anaesthesiologist: *In the old fashioned anaesthesia charts you had a considerable element of subjectivity. If I am to be entirely honest – which one should; most people should – there really is certain subjectivity when you register by hand. There is. In an ICU chart – electronic – there is no subjectivity, but there might be considerable sources of error. And those you have to weed out. If you don't, those that read the charts must interpret them. And that... I don't believe that is a big problem. You have to be skilled in anaesthesia to read an electronic chart as well. You mentioned one example of an erroneous measuring – it is not hard to imagine other examples as well. But they have to be interpreted in light of the context. If you don't, you won't get it right. I believe we have an unsurpassed documentation of the operating rooms today. We didn't have that previously. It is not just the subjectivity that entered the anaesthesia charts* […] *I'm not saying that people cheat with the anaesthesia charts – that's not what I am saying at all. But there is a certain subjectivity and a level of erroneous notations. This is not necessarily serious, but it could of course be.*

What the nurse depicted as pragmatism and contextual knowledge is by the doctor here depicted as (unwanted) subjectivity. This is not coincidental, but relates to the different purposes of the practices in which the information takes part:

Me: *Some might call it professional discretion?*

Anaesthesiologist: *Yes... if you mean that on a chart with a timeline and an axis where you should note exact values like pulse and blood pressure – then this is not professional discretion. It is exact values. And* that *is what this software does for us. Of course you need to weed out erroneous registrations, and you can very well do that. But that is a tiny, tiny problem compared to the* weighty, exact *documentation we get from this. And* that *is what I like about it. It's black on white. If I on the way have had a blood pressure down towards forty – it says so black on white, and it is recorded in a weighty database where it can be retrieved at any time. I think that is important. And we have* far from *realized the potential benefits for anaesthesia. At the moment we only use the software for quite general statistics, like "amount, when, type" and so on. But if I had the time, I could for instance retrieve* all *operations of* this *kind during the last few years – all the liver transplants. Then I could really make some interesting statistics. What kind of drops in blood pressure do we get during the operation? How* deep i*s it? How long does it* last*? Which* interventions *were done? All such things could* very *easily be read out of this... if you took the time to do it. I would really like to do it, but*

everything takes time. But this is the kind of tasks this could be used for – entirely impossible *with the old system. And not just to display statistics, but in order to learn something from it. To teach ourselves.*

Me: *Maybe research as well?*

Anaesthesiologist: *Yes, that is what I am talking about. We could make it prospective and properly. Those are the things that move us along – you have to learn from your mistakes, but also by that which works. If you ask me, I'm in no doubt that we have come far, far ahead in respect of documentation – documentation of data from the operating rooms. And I hope we will get there in ICU as well – I can't understand why we shouldn't.*

Precision, as depicted here, relates to how well representations can be produced that accurately and reliably accounts for the quality of the section's procedures; for better and for worse. Achieving this requires several steps of aggregation. First the recorded blood pressure measurements must be collated with records of other clinical variables and interventions. Next, single patient trajectories are collated in order to compensate for variations and enable generalizations. This aggregation depends on the elimination of subjectivity in the production of blood pressure in order to commensurate with the scientific ideals as expressed by the anaesthesiologist.

The examples provided here are partial accounts of how the meaning of precision differed for two of the clinicians affected by the project, both in relation to the production and use of blood pressure measurements. For the project to succeed in its intentions, such differences must be taken into consideration and somehow managed, not just for these two, but for the rest of the clinicians in the hospital as well. Should such diversities be supported or obliterated by the new system and the alterations in work practices that follow? The material suggests that some variations, though maybe significant, are not really needed; sometimes similar things are different simply because they don't share a common history, often due to earlier divergences. Such differences might be obliterated without serious negative effects. Other times, variations are expressions and results of – if not deliberate, than at least understandable and sensible – adaptations; differences that are encouraged or even required by context and contingencies. Such differences probably *should* be supported, as they are there for a reason. The main problem for any (ICT based) change initiative in healthcare settings is of course to tell the difference; what can and should be standardized and what ought to be left free to local adaptations and variations.

More specifically to the case, for the electronic medical charts project to succeed in its intentions, all uses of blood pressure in (and for some purposes even beyond) the hospital would have to be reconciled into a single representation. This representation would have to produce a precision good enough for the entire range of purposes. To do this it would also have to assimilate and translate the different ways blood pressure was being produced across the hospital.

5 Discussion

From a practice view, precision in blood pressure measuring has different meanings in different contexts for different professions practicing within different disciplines. It is not the same for the head of the anaesthesia section as it is for the intensive care nurse in the thorax surgical department. Precision in blood pressure measuring is – to use the terms of Annemarie Mol (2002) – a multiplicity; it is more than one, but less than many. This multiplicity is also reflected in the way precision is produced. Different constellations of the hybrid collectives, by which the achievement of precision is accomplished, have evolved over more than 250 years into the variety we find today. And now, with the introduction of ICT systems for electronic medical charts, the next evolutionary step for (some of) these collectives seems to be emerging. As this process entails a homogenization of the material artefacts involved, precision must be renegotiated to be able to circulate across the different collectives and their practices. A new inter-subjectivity must be established; flexible enough to work in multiple localities, yet robust enough to be representable in and by a single ICT solution.

This is not simply a matter of 'good enough' precision (though sufficing is also a relevant issue); it does not matter to the ICU nurse whether the pressure is 100/60 or 105/60. But it matters if it was 120/60 five minutes ago, and especially if this represents a persistent trend of falling pressure or if an intervention that could potentially influence the pressure was performed during the last five minutes. This is not about the 'subjective' interpretation of 'objective' data, but rather about the *situated* enactment (and purpose) of precision. In this context, precision is (re)produced by the inclusion of delta values and correlations with other measurements, fairly indifferent to the resolution or accuracy of individual representations. Based on this precision, decisions are made and interventions performed 'on the fly', in order to prevent any deterioration in the patient's condition. The nurses know, by experience, the contextual factors that influence this precision, and are able to adjust accordingly whenever needed; precision at the CVS is achieved by temporarily stopping the IV fluid – precision at the arterial catheter is disturbed when drawing a blood sample. Judgement in the production of precision includes this knowledge, but passing this (contextual) knowledge on to the next context (thus supporting continuum of care) is currently *not* supported by EMC, nor is it an intention to include it. Thus handovers from one context to the next currently represent a major challenge.

In the ICU unit, the medical charts take part in preventing deteriorations in the patient's condition during the first critical phase of the body's healing process. In the operating room they are engaged in a different practice for a different purpose; that of keeping the patient sedated in a safe way for the duration of a surgical intervention, and monitoring that neither the anaesthesia nor the intervention causes any damage to the patient. But while the charts are intrinsically entangled in the ICU practices, they are in the OR primarily delegated the role of documentation. The paper or the screen is not necessarily positioned within eyesight of the nurse or the anaesthesiologist, as they base their decisions and interventions directly on what they read from the scope. At any given time, there is only one patient in the OR, so they *know* what previous measurements showed and in what direction the patient's condition is developing. If in doubt, they can of course consult the charts, but in practice they rarely do. The one-to-many in caregiver/care receiver relationships in the ICU is replaced by many-to-one relationship. As such the complexity any single caregiver must manage is considerably reduced when compared to the ICU. The charts can therefore be left to the task of documenting, rather than taking part in the handling of this complexity. Thus precision becomes more related to what is needed for documentation purposes only.

We can identify multiple actors in the production of blood pressure measurements, rendering the simple parity of human and non-human actors as well as that of instrumented versus non-instrumented measurements insufficient as both descriptive and explanatory models. On the human side of this, we can distinguish not only between different professions and disciplines, but also between the different human senses invoked in different practices involved in the production of blood pressure. This includes the surgeons and anaesthetists in Moreira's story as well as the nurses in mine, but also the distinction between the tactile, audible and visual perceptions mobilized and aligned with the different technologies involved in the different practices. The tactile perceptions embodied and enacted through the practitioners' fingers are today in most practices, due to technological developments, supplemented by an inflatable cuff and the stethoscope or different versions of analogue and digital electronic devises and gauges. Finally, the means for recording the resultant information also include a variety of different tools and techniques, ranging from daily or hourly notes on paper sheets to continuous and more or less automated computerized registrations. These distinctions, as well as their aggregates, constitute a heterogeneity that *matters* – in several different ways. Moreira foregrounds the quest for precision and thus offers a very illustrative aspect of *how* this heterogeneity matters.

Precision in the production of blood pressure, Moreira suggests, is both significant to and symbolic of the "scientification" of medicine. This makes a lot of sense in a world where ever increasing medical specialization continuously limits the scope of single practitioners. But precision is not an unambiguous size that can be judged on the basis of the simple parity of instrumentation versus non-instrumentation. It is not a duality, but a multiplicity, produced by different configurations of what Marc Berg calls *hybrid collectives* – communities of mutually interdependent socio-material actors,

where roles, coordination of roles and the aggregation of what they produce are deeply embedded in, and subsequently enacted (and thus maintained) through, several different heterogeneous practices. And it is also a continuum, where *time* and *timing* become important aspects; precision in the production of blood pressure relates not only to the meter but also to the clock.

Ontologically the production of blood pressure is a step by step translation of the forces of a muscular contraction into formal representations, and thus depends on multiple transformations and subsequent intermediaries along its route into the epistemological domain. This multiplicity equals that of the production of arthritis in the lower limbs (Mol 2002); different socio-material collectives produce different intermediaries with different impacts on precision. To the stethoscope, blood pressure is a physical movement that is transformed into a sound wave. The same movement is by mercury translated into its own movement inside a glass tube, where precision depends on the width of that tube. For electronic measuring devices, the physical movement caused by the force of the heart's contraction is translated into a corresponding movement of electrons – intermediary represented as voltages and currents – in preparation of the next transformation. At this stage analogue and digital technologies diverge in the production of representations and subsequent precision. While analogue gauges leave some interpretive responsibility to human vision in reading the position of the needle in relation to the adjacent scale, digital representations does not afford this. Thus the production of precision is left to the software; how many decimals are recorded and how often? But black boxing precision like this foregrounds *reliability* as an aspect in the production of blood pressure. When the laws of physics applied in the transformations of blood pressure become less transparent, human discretion is skewed towards the task of trusting or doubting the technology rather than the interpretation of its representations. This is also a push towards a corresponding digitization of the human factor, where the open question of *what does this mean* is transformed into the closed question of *do we trust this or not*. The digital by definition only has two states, thus making it incapable of rendering the nuances of human perception. Still digital representations are often attributed with superior precision; not necessarily based on what they *are* but rather because their form and modus of operandi makes them hard to challenge. They thus often seem to resemble cases of security by obscurity; either you trust them or you don't, and if you don't you have a problem. And who wants problems?

Precision is by definition related to *formal* representations, pointing to the representation's accuracy. Because accuracy can mean different things in different contexts, the assessment of precision thus also depends on the intended use of that representation. This is also reflected in the different practices that produce such representations. In clinical contexts, blood pressure is not measured for its own sake; rather it is one of several *vital signs* that are monitored as indicators of a patient's condition. In some settings they are *continuously* monitored; as indicators of how the patient's condition is *evolving*. Precision thus also depends on how well these indicators represent current status and changes in this condition. This again depends not only on the way indicators are measured, but also on the very *choice* of indicators for different contexts and conditions, as well as the different calculations and methods employed to compensate for such differences.

6 Conclusions

The introduction of new technologies implicitly comes with the assumption that the technology will be able to produce precision on its own (Wise 1995). This contribution illustrates how the production of precision highly depends on the social, as this is where precision is determined, based on its use and purpose. But the production of precision also depends on the materiality of the technology. Producing precision on paper is very different from producing precision on a computer, and the precision(s) produced will differ. Thus precision can only be understood as an accomplishment of hybrid socio-material collectives.

Unwrapping the multiplicity of precision as well as the complexity of its production implies the significance of decisions made (and not made) during the entire lifecycle of the technologies involved

in this production. Thus it illustrates why decisions based on a notion of precision as a single linear size often will clash with the practices in which the technologies take part. That this has practical implications for the design, implementation and use of information systems is evident. For one, it strongly indicates that the quest for the right information in the right place at the right time should be placed under a more nuanced and humble regime, where questions such as those put forward in this contribution might be explored.

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