Heat, Fire and Temperature: The industrial revolution and HCI

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Abstract
HCI has many challenges and internal debates (for example, where is our theory? What is the role of design in HCI? What is the relationship between research and practice? How do we make an impact?) that recur at the CHI conference and that students either ask themselves or find they are asked by others.

This paper takes a historical look at this issue and describes some of the discoveries made during the industrial revolution about heat, fire and temperature (the development of thermodynamics) and how these discoveries were made.

The parallels to human-computer interaction today are explored with two primary intentions:-

1. to show how important it is that we continue to debate and investigate the precise nature of concepts we take for granted (e.g. usability, user interfaces, user experience), and
2. to illustrate how practice contributes to the development of theoretical concepts.

Keywords
theory, history, HCI, user interface, usability, user experience

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

The Industrial Revolution is not a topic which comes up frequently at CHI conferences and if it does it is more likely to be in relation to the scale of the social impact, rather than in relation to the development of our profession.

And yet, the Industrial Revolution was a time of great engineering and scientific achievement, increased productivity as well as massive social changes and disruption. There were pressures on production that required better and better machinery and movements of people that changed traditions of food production and delivery. And all this at a time when weaponry was advancing, empires were growing and wars were occurring on a larger scale.

There are many things we might learn today from that time – some of them obvious such as 'lets not forget the importance of human considerations as well as economic ones" and others less obvious, such as the complex relationship between science, theory and practice.

It is this latter area that I wish to explore in this paper. In particular the events, people and activities that were to give rise to the area of thermodynamics. In exploring this area we will not only see how the distinctions between theory and practice played out (distinctions that impede the progress of HCI today), but we may also gain a clearer sense of some key missing elements in HCI theory.

You may be wondering 'why thermodynamics?' Rather than time or quantum physics, say?

The answer is that it represents developments that were among the first to deal with messy imperfect systems, which created new unfamiliar engineering challenges. In particular thermo-dynamic systems tend to be irreversible (e.g. the burning of fuel).

This kind of wicked problem seems like an appropriate place to look for historical insight into our own field.

Heat, Fire and Temperature

Central to the development of the industrial revolution was the developing understanding of the nature of heat, fire and temperature. Controlling heat was essential to the creation of efficient steam engines, to large-scale brewing, to warcraft and moving food from rural areas into the developing cities.

In ancient Greece, fire was seen as one of the three or four primary elements (earth, water, fire and maybe air) and Hippocrates in 460BC commented that heat is "a quantity which functions to animate, (which) derives from an internal fire located in the left ventricle."

Although it was known that heat flowed, the idea that heat was motion was not proposed until the 12th century. Gradually people came to understand that heat was about vibration or motion of particles and that temperature was, in some way, a measure of that motion.

Hot and cold were still thought of in different ways - hot was a property of a thing, temperature was a measure of that property and cold was thought to be the absence of that property.

Furthermore, temperature researchers had no consistent point of reference (body temperature, the boiling point of water, the melting point of butter were all used) – and with no clear sense of what they were measuring, or of what the reference points should be, developments in technology were hampered.

And finally, fire was seen as a source of heat, and (importantly) one that ended up exhausted.

These 'old' ideas may or may not qualify as a theory but they had been an adequately working framework for many years. However, the arrival of the industrial revolution created pressures that required that the concepts be comprehensively understood and distinguished.

If, at this point, you are asking yourself why there should be such analogies, then I can only say "Good question!"

But in so far as there is an answer it lies in the Landauer challenge and in the sense that we are solving an equivalent problem to that facing the engineers of the 18th and 19th centuries. We can build the fire and design the steam engine and we can measure temperature, but some key concept in between is still needed to enable us to solve the problem of creating useful, efficient systems.

Feel familiar?

There are some clear analogies that can be drawn to HCI at this point and that may begin to point the way to some insights from the past.

Fire is the most tangible of these thermodynamic concepts and the obvious analogy to our world is that of fire as the user interface (or computer system perhaps, or software). It is the tangible element, the one that we build and the one that can still be mysterious. Consider, for example, Tom Landauer's classic "The trouble with computers" [7] which so clearly revealed the problem that although we know how to build fire and maybe how to build a steam engine, we are still a long way from understanding how to use such capabilities efficiently.

Temperature, as a form of measurement, has an obvious analogy to usability, also a form of measurement. And the fact that we don't really know what our reference points should be for usability intriguingly parallels the fact that early thermometer builders also had no idea how to identify a reference point, or how to assess the precise behavior of their materials. Thus we have cognitive walkthrough [9], cognitive modelling [1], heuristic evaluation [8] and usability testing and only a handful of studies helping us understand how they compare or what they measure [5, 3].

But, heat? What is the analogue of heat? At this stage of understanding there is no easy answer – it was only later that a clear concept of what heat was began to emerge. Furthermore, the obvious candidates (user-friendliness, usefulness, effectiveness) all seem like qualities of the fire, rather than the mysterious heat itself. What kind of thing is heat? and what (in our world) has the same nature?

It is worth noting that all three of these candidates for heat are actually candidates for 'hot' - they are the quality of having positive 'heat'. And there is no real world for 'cold' in our HCI-world – we don't have real words for not useful, or user-unfriendly, or ineffective.

Now maybe there never will be an equivalent of 'heat' in HCI and maybe 'hot' is the really important concept for us. But I want to go forward for the rest of this paper with the notion that we should be striving for something more. This is a 'what if …' paper – I'm not trying to persuade you that these analogies are true (whatever that means) or that more likely that their implications must be true, but that the implications are interesting and inspiring and are, therefore, worth our while exploring.

The industrial revolution and thermodynamics

Heat and temperature

One of the first developments in the understanding of heat was when James Black, in 1761, showed that ice melted by absorbing heat and yet it didn't change temperature. What this showed was that temperature could not be thought of as a measure of heat – an idea that is, I think, still shocking today. And drawing on our analogy above, it makes me wonder whether we really know what usability measures?

Water wheels and steam engines

In 1783 Lavoisier demonstrated the importance of oxygen in burning and proposed the 'caloric' theory of heat in which 'caloric' is a weightless invisible fluid that moves between objects when out of equilibrium. Caloric was even considered to be an element equivalent to oxygen or copper.

There was also a theory of frigoric – the cold equivalent of caloric – but in general the prevailing view was that cold was simply the absence of caloric.

In this confusion one can see very clearly the struggle to know whether it was 'heat' that had to be explained or 'hot' and 'cold'. They are undoubtedly closely related, and hot / cold are much more perceptible than 'heat'. For many people understanding hot and cold was thought to be sufficient, or maybe equivalent to understanding heat.

Such a model may seem quaint to us today but it was highly influential and in fact, despite being incorrect, it effectively gave rise to the second law of thermodynamics. The problem context for Lavoisier and for Carnot (sometimes seen as the father of thermodynamics, or the founder of the second law of thermodynamics) was steam engines, power and efficiency and the analogues that they worked with primarily were waterwheels. They were heavily influenced by the idea that power was created by the flow of a substance down a gradient.

In 1824 Carnot published "Reflections on the motive power of fire" [2] which drew on caloric theory in order to articulate the underlying principles behind the efficiency of heat engines. He realized that it was incorrect to say that power came from the consumption of caloric, but that it derived from the transportation of caloric from a hot body to a cold one. Even though he used the wrong theory his fundamental insights turned out to be correct and therefore highly influential.

Carnot's work is a great example of a practitioner (he was more concerned to affect the efficiency of heat machines than to use or develop the theoretical underpinnings) making a profound contribution to scientific theory. His assumptions about the materiality of heat (i.e. that heat is caloric) led to some seriously incorrect conclusions (e.g. that "the same quantity of heat is stored in the refrigerator as left the furnace"). And yet most of his correct and profound insights derived from reasoning within this materiality - heat as a water which falls from high to low, but which is fully preserved across the drop.

Even though there are reasons to believe his choice of caloric theory may have been pragmatic (the introduction to the 1897 of his book suggests he was aware of data repudiating caloric theory, but also very conscious of the fact that caloric theory was the dominant view in 1824), his book (when it eventually came to light 10-15 years later) enabled caloric theory to remain a dominant force for another 75 years.

Making cannons for war

The demonstration that caloric theory was wrong had happened 27 years earlier in 1797, when Count Rumford was working for the Bavarian army making cannons. Making a cannon was a laborious process of casting a solid cylinder of metal and then boring out the cannon. Rumford, too, was a practitioner and his concern was the heat generated when boring out a cannon. His 'experiment' in 1797 involved boring out a cannon with a dull drill bit with the main bore immersed in cold water – in under 2 ½ hours the water was boiling.

To us the importance of this is hard to appreciate, and it is tempting to assume that many dismissed the finding as obvious (given that friction was known and to some degree understood). However, reports from 1797 indicate that the audience was astounded that water could be boiled without the use of fire.

The fact that these demonstrations did not affect caloric theory is due to two reasons that seem to resonate through to the present-day:

1. Rumford was very much a practitioner and had no theoretical alternative to caloric theory
2. Rumford's practical studies were (claimed to be) full of methodological issues and anomalies that made the results questionable.

Besides warfare, brewing and steam engines, there were also developments around the same time in ice-making and refrigeration. For example, the increasingly urban population required food brought to them and that created the need to keep food fresh for longer periods of time.

It should also be noted that steam engines were used for numerous different domains from pumping water out of mines to transportation and many others.

Brewing

The next (and critical) breakthrough came in the world brewing and the work of James Joule – the owner and manager of a Manchester brewery. Science was a hobby of Joule's that he enjoyed applying to the challenges of brewing, and electric motors in particular were a new and fascinating invention (1821).

His initial focus was applying science to help make the business about whether electric motors would be better than steam engines for providing the heat and energy required for brewing. Such a precise question led Joule to focus on precise measurement as a critical element.

Inspired by Rumford's work, Joule built an apparatus to heat water by agitation (the controlled rotation of a paddle in a closed container of water). By carefully controlling the number and speed of rotations and measuring precisely the temperature of the water, he was able to demonstrate categorically that heat could be created by mechanical work.

Indeed, he went further, being able to calculate the mechanical equivalence of heat – the idea that a given amount of work will always create the same amount of heat. He showed that the gravitational potential energy lost by the weight in descending was equal to the thermal energy (heat) gained by the water through friction with the paddle.

Although it took many years for these results to be fully appreciated, Joule's work (c. 1843) marks the transition from caloric theory (heat as an entity) to kinetic theory (heat as a form of energy).

Clausius, in Germany around 1850, showed that almost all of Carnot's work could be re-expressed in terms of kinetic theory with very few changes. Fundamentally the key change was from conservation of heat (caloric) to conservation of energy.

Late 19th century

Although thermodynamics continues to develop from 1850, after Joule's discoveries it acquires a greater emphasis on scientific investigation.

The practical arena for the latter half of the 19th century became refrigeration (and the problem of transporting food to the new urban populations). Strikingly, the discoveries here are much about technologies for the control of cold than they are of new ways of thinking about what cold is.

Back to HCI

The story of thermodynamics is complex and it is hard to do it justice in a few non-technical pages. However, the important point is how the concepts and the theories were in a state of flux; key breakthroughs were made using the wrong theories; practitioners within different domains trying to solve their real problems contributed many of the key insights.

But besides these important observations, I find an intriguing sense of parallelism between the world of the industrial revolution and thermodynamics and the present-day world of HCI. No answers come out of an exploration of these parallels, but there do seem to be many questions that deserve answers.

Before explicitly articulating the parallels, we should consider what kinds of entities are involved:-

- **fire**: tangible, a component
- **steam engine**: tangible, a system
- **heat**: intangible, a transfer of energy
- **temperature**: a perceivable measurable property

Temperature
The easy parallel is the mapping from temperature to usability - usability as a perceivable, measurable property of an object. This seems indisputable, except that we usually use 'usability' to mean good usability, which would imply that usability should map to 'hot'. In this sense, usability is a quality whose value can be perceived and measured – the equivalent of temperature would then maybe be 'user-friendliness'.

This 'if' begs a large number of questions and may upset many readers. But the intent is to sidestep these questions …

- 'the desired results' does not say desired by whom
- 'achieve' does not address who decides when they are achieved
- 'effectively or efficently' does not address how these would be assessed

These are seriously large questions and for now I want to simply allow all or any answers – it is not in the scope of this paper to deal with them.

This soon reaches a point which feels like pure semantics – but the realisation that there is temperature **and** there is hot / cold, leaves HCI with a tricky question about what kind of thing we think usability is (or should be). Is usability a measurable property, or is it a particular value on that scale?

Fire and Steam Engines
If our goal is to better understand how to build and drive computer systems so that they achieve the desired results more effectively or more efficiently, then fire should be the element that drives the engine. Immediately this gives us the idea of the steam engine as the computer system (or software or website) and the fire as the user interface. Such a mapping certainly makes sense across the different domains of application – the steam engine exists in just one domain, but fire is common to all of them.

However, this parallel seems to leave the user – the human – right out of the system; out in the cold, so to speak. That might have been acceptable in the Industrial Revolution, but not today. That might have been alright for the development of thermodynamics, but not today for HCI.

Is there an alternative parallel we can draw? What about if we consider the fire as the computer system and the steam engine as the human-computer system? This seems to be a much more appropriate parallel, with the user interface best thought of as the fuel for the fire.

In this parallel it is clear that the fire (the computer system) has a temperature (a usability), but that the steam engine (the human-computer system) does not. What this system does have is an 'efficiency' or an 'effectiveness' (or maybe a worth or a usefulness).

In this way one can immediately see that usability cannot be everything – that, for example, value-centered HCI (or worth-centered HCI [4]) is not really a dramatic shift from one paradigm to another, but the addition of a new perspective.

A science (or at least a discipline) of HCI needs to know how to build and measure fires and how to build and measure steam engines and the same tools cannot be applied to both.

Heat
And yet there is a still deeper challenge … what is our parallel for heat? The big breakthroughs in thermodynamics during the Industrial Revolution came from the developing concept of heat as the key underpinning concept. Has HCI found its equivalent of 'heat'?

Heat is an intangible; it exists in the transfer of energy between objects of different temperature. There is no simple, obvious parallel (there is no concept of transfer between objects of different usability), but there are maybe some thought-provoking possibilities.

The most appealing (to me) is heat as the user experience. It is intangible and it has strong sense of 'transfer' (it only exists between things, over time and in a certain context and relationship). In drawing this parallel one may notice the fact that user experience - like heat - is more of an event than a quality.

Another element of this parallel is the idea that heat cannot be created only transferred from another form of energy. In the same way a user experience cannot be designed or created, but the potential for a user experience can be created.

In drawing out this parallel the notion that usability and user experience are different terms for the same thing seems to fall apart – they are fundamentally different types of things.

Furthermore, a strange wrinkle is the fact that heat only flows in one direction (from hot to cold) which makes one ask whether user experience similarly flows only one way and if so, which way? Also heat flows by different methods (e.g. radiation, convection and conduction) and at different rates – does user experience flow differently? What are the conductors and insulators for user experience?

Therefore …
My intention in drawing out this conceptual parallels, as well the historical process parallels is to show that we can learn and discover from exploring the development of concepts in other domains.

It would be foolish to try to make strong claims for these parallels – their intention is to provoke new ideas, not provide answers. It is entirely possible that another author could write a similar paper on the parallels between HCI and the discovery / understanding of time and relativity, but such a paper could not contradict what is in this current paper. Indeed, i believe we need more such explorations that can encourage us to look very closely at the concepts we so take for granted and help us see them in a new light.

Truly back to HCI!

One of the commonest complaints against Human-Computer Interaction (HCI) is that it is atheoretical, but there has been little public discussion about the kind of theory that is missing. Or about what exactly the problem is with being atheoretical?

Discussions about theory in HCI seem to cover a variety of different things:-

- theories from neighboring disciplines which may be relevant (e.g. activity theory [6])
- philosophical approaches to HCI (e.g. constructivism)
- theories within HCI (e.g. Claims theory [10])
- rejection of theories in favor of engineering principles

These discussions usually leave me with the feeling that there is no shortage of 'theory' flying around, but that it isn't helping to get the job done. Complaints against HCI usually mean that we feel that there is more impact to be had than we are currently having. Or maybe, the complaint of atheoretical-ness is a lazy shorthand for the problem that we have no way of telling a useful (good) theory from a bad (useless) one.

In this paper I have tried to explore a historical perspective that can make us feel better about where we are and help us to see what still needs to be done. I have deliberately not offered the answer (the theory) that the atheoretical worriers are crying out for – rather I have explored what it might mean to be more theoretical.

Take-aways

This paper is intended more to prod, poke and inspire than to teach or inform – but even so there are a number of critical messages that should be taken away from it:

1. that we should be cautious of assuming that our key concepts in HCI are defined and understood. In particular we have not taken care to articulate what kinds of things our key concepts are. In this sense it is very true that HCI is atheoretical – we deploy lots of other theories, but we dont do much to develop our own.

2. that there is an implicit question to be asked (answered) about whether we are free to make up, define and label our key concepts, or whether there are some (at least some) concepts that truly exist to be identified and understood.

3. that advances in our understanding of our field will probably derive from a complex blend of both research and practice. Furthermore, they will almost certainly have to draw on numerous different contexts of application.

4. that we should spend less time discussing which of the various perspectives on HCI is correct (e.g. mental models, activity theory, distributed cognition, value-centred-HCI) as though our task is to choose which is the most appropriate for our problem and more time trying to understand what might be the underlying elements of a world in which all these different perspectives could simultaneously appear to be true.

5. that even if you believe that HCI can never be a science (like thermodynamics) there may still be a lot to learn from examining the history of areas of science that have had a huge impact on technological development. Indeed it may be that the history of science will have more to teach us than the history of the technological developments themselves.

Back to the Top

Briefly, before closing, it seems worthwhile to return to the HCI issues with which we opened.

Where is our theory? All around us, but buried! Indeed, the conclusion I come to after this intellectual exploration is that we really haven't yet worked out what our theory would be of.

What is the role of design in HCI? Central, but only alongside many other central elements. Our expertise (our theory) can only be delivered and appreciated through delivered technologies and these must be designed. But numerous other elements are equally critical to enabling those designers to access and use our expertise.

The relationship between theory and practice? Inextricable! And complex – practice drives theory and theory drives practice. Practitioners have major insights that can impact theory and theoreticians invent technologies and create tools for practitioners.

Making an impact? Keep our eye on the ball! Stay curious and remain open-minded.

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