Touching Technology
taking the physical world seriously in digital design

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Abstract

Although we live in an increasingly digital world, our bodies and minds are designed to interact with the physical. When designing purely physical artefacts we do not need to understand how their physicality makes them work - they simply have it. However, as we design hybrid physical/digital products, we must now understand what we lose or confuse by the added digitality. With two and half millennia of philosophical ponderings since Plato and Aristotle, several hundred years of modern science, and perhaps one hundred and fifty years of near modern engineering – surely we know sufficient about the physical for ordinary product design? While this may be true of the physical properties themselves, it is not the fact for the way people interact with and rely on those properties. It is only when the nature of physicality is perturbed by the unusual and, in particular the digital, that it becomes clear what is and is not central to our understanding of the world. This talk discusses some of the obvious and not so obvious properties that make physical objects different from digital ones. We see how we can model the physical aspects of devices and how these interact with digital functionality.

Introduction – Physicality

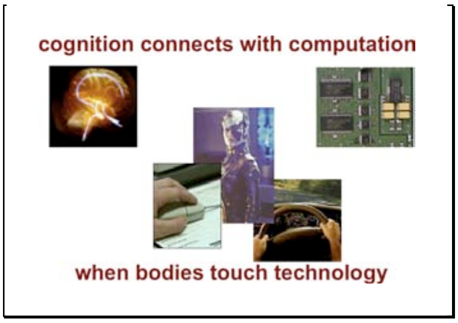
Background

I am part of a collaborative project with others at Lancaster and designers in UWIC, Cardiff called "Designing for Physicality" (DEPtH) [[DE09]] This has been funded by a UK national research programme "Designing for the 21st Century" [[AE09]], which is itself a collaboration between AHRC, the UK funding agency for arts and humanities and EPSRC the funding agency for science and technology. This is an exciting initiative with work from fashion to architecture, but within it our focus is on the nature of physicality and how it impacts product design.

In fact aspects of physicality have long fascinated me (for example see [[Dx00, Dx09, DR00]]), but the DEPtH project has been both a personal focus and also an opportunity to learn more.

As well as the project itself there have been a number of workshops around the issues of physicality [[GR06, RD07, PF08]] and a journal special issue [[RD09a,RD09b]].

Why Study Physicality



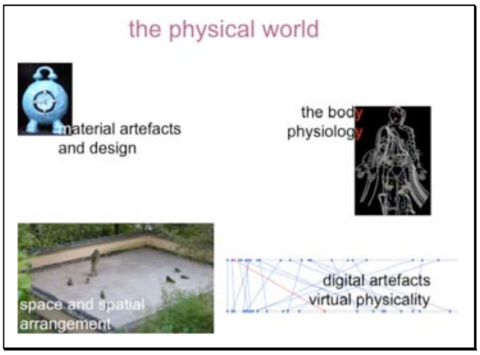
Historically there has often been a dualistic view of mind and body with cognition and thought being seen as quite separate from physical muscle and bone. Computation has a similar abstract feel, a world of algorithms and pure reason.

However, both are embodied in flesh and silicon, and if we wish to communicate with any computational device, we do so through the physical world whether tapping keys, pushing a mouse or stroking an iPhone screen. Not all these interactions involve fingers and touch: speech involves tongue and mouth creating pressure waves through the air that vibrates the microphone in the computer, gesture recognition involves moving arms, photons and optics, and even direct brain interfaces use electrodes and wires. There is no connection in pure abstraction but always in the physical world.

As more devices around us have digital aspects, it becomes essential that we understanding the way physical and digital interactions meet. Traditionally the physical form of a product was the domain of the product designer whereas the digital interaction belonged to usability or human–computer interaction specialist. However, now, in products from mobile phones to washing machines, the physical design and the digital design must come together to create a single experience for the user.

Components of the physical world

The world can be seen in many ways, by biologists, physicists, geographers and more. Focusing on those aspects that influence the design of hybrid digital/physical devices, we can look at four main aspects.



- *material artefacts and design* – The world is full of 'things' both natural things such as stones and constructed things such as scissors, books and mobile phones. Our understanding of the former is obviously germane to the design of the latter. We return to this later in the talk.
- *the body and physiology* – As noted, our bodies are physical as are our brains; however numinous our thoughts they have their life in the material substance of neurons. Our bodies too can be part of digital interactions, whether gaming in the living room with Wii or using an advanced gesture recognition interface. The physicality of body and brain is also discussed later.
- *space and spatial arrangement* – When we interact, we do it in physical space. This space may be where we perform physical movements – living rooms have been reorganised to accommodate the Wii [[No08],VG08]]; but also has social dimensions. For example, at Lancaster we have the Hermes systems, small displays outside our office doors where visitors can leave notes [[CF03]]. We have never had problems with abusive messages, which is probably because anyone leaving a note is aware that they could be observed in the public corridor – the spatial location changes use [[DC04]].
- *digital artefacts and virtual physicality* – Sometimes we emulate aspects of the physical world in the digital: virtual reality creating whole parallel worlds; the desktop metaphor; dragging images in an iPhone; or even the idea of 'visiting' a web site. Do we understand enough about the physical world to be able to capture the right aspects? And computation itself is embodied in silicon and magnetic surfaces and bound by that materiality (see also the PalCom project "making computing palpable"[[PC08]]). There can only be a finite amount of computation in a finite space, and information flows take time, hence the star like pattern of supercomputer circuits. Even the Turing machine can be thought of as a *touring* machine as any physical attempt to pull an infinitely long tape would break the tape and the machine instead needs to traverse a fixed tape – the tape embodying finite information in finite space and the machine with finite computation.

Of course the world is more than these things, there are animals and plants, fire and storm, but the above four seem to be those most intimately connected with digital devices … although there have been proposals to help people interact better with their pets! [[TL06, Mc09]]

Different ways to touch

There are a number of different research areas, which study the meeting of physical and digital worlds.

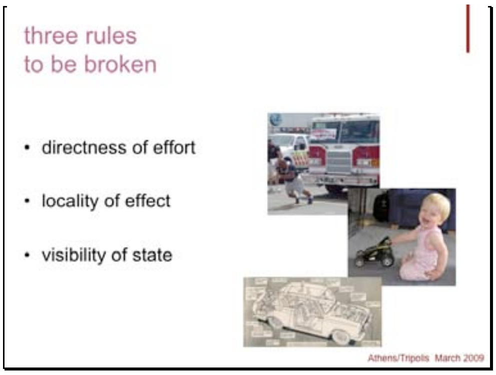
- *ubiquitous computing (ubicomp)* – In Weiser's vision of computation permeates the world, woven seamlessly into life [[We91]]. In fact, technology often does not so seamless, but certainly both our body-load of devices and the number of digital devices in our homes suggests that they are ubiquitous if not invisible.
- *tangible user interfaces (TUI)* – In contrast, tangible user interfaces attempt to make computation both visible and touchable, where physical tokens represent digital things, embodying computation [[IU97]].
- *mobile* – Of physical devices in day-to-day life, it is probably the mobile phone that has transformed lives most over recent years. Mobile applications can be divided into two main categories: (i) those were location doesn't matter and (i) those where it does [[BC07]]. This sounds like a tautology, but is a little more subtle! The first are those such as phoning, or accessing the internet, where the crucial thing is to transcend location. These are less interesting for the topic of this talk. However, the other category is very relevant, when the physical location of the phone is central to the application as in maps, or 'find a friend' applications.
- *virtual reality* – Whereas ubicomp, TUI and mobile applications all involve actions in the physical world, virtual reality attempts to emulate the physical world within a digital environment. This may be a representation of a real or planned physical setting, as in tourist applications or an architect's fly-through; may create a realistic, but artificial world as in the Sims or Second Life, or may use a physical world metaphor to represent information artefacts as in the computer 'desktop' or more sophisticated systems such as the Tower project that created an urban city-scape where each building and area mapped to files and folders [[PP04]].
- *alternative reality and mixed reality* – Alternative and mixed reality systems blend the physical and digital worlds, overlaying digital imagery or other outputs (sound, tactile) on top of the real world, using spectacles, projectors or mobile devices. Core to all is that there is some form of registration between physical and digital worlds, not merely that digital content can be accessed anywhere (similar to the distinction in mobile applications).
- *physiological computing* – While most of the above use the physicality of the device and the world as their connection point to the digital, there are also those for whom their very body has become the computational device. In assistive technology, small muscle movements (and in the future nerve impulses) are used to drive prosthetic limbs. Physiological signals such as heart rate can be used in therapeutic settings or even to modify control gameplay [[GD05]]. Notably Keven

Warwick has famously (or infamously) voluntarily embedded chips in his body in the belief that our future as humans will be cyborg [[Wa03]], and artists such as Stelarc have explored this in performance [[ST09]]. We will return to these issues later.

- *product design* – Finally, and at the prosaic end of these visions of our cybernetic future, are the mundane devices that fill our homes and pockets which have physical form and digital aspects: MP3 players, phones, washing machines, and Tom Toms.

Understanding Physical Things

When teaching software engineering, I use three 'rules' of physical things to help explain why it is harder to design software than many physical things:



- *directness of effort* – Small effort produces small effects, large effort produces large effects. If you push a pebble a little, it moves a little; if you push it a lot, it moves a lot – simple Newtonian dynamics.
- *locality of effect* – Things effects of actions where and when you do the action. If you push something and then it moves later you are surprised and only a magician would try to move something without touching it.
- *visibility of state* – Physical objects have complex shape and texture, but this is largely static. The dynamic aspects of state are very simple: location, orientation, velocity and rate of angular rotation. However, as humans we are not very good at assessing even the latter of these!

These rules do have exceptions. For example, if a rock is precariously balanced a small push might send it rolling down the hillside (breaking directness of effort). Or if you accidentally put a glass down on the edge of a table and turn round you may be surprised to hear it fall and shatter a few moments later. The interesting thing is even these very natural breakings of the rules cause us surprise, or like magnetism's action at a distance, seem like magic.

All of these rules are *systematically* broken by human technology, and in particular digital technology, consider a mobile phone:

- *no directness of effort* – Dial one digit wrong and you may ring someone in a different country, not just next door.
- *no locality of effect* – The whole purpose of a phone is to ring people up – spatial non-locality; the alarm you set at night and then rings in the morning – temporal non-locality; and text messages break both spatial and temporal locality!
- *no visibility of state* – The phone is full of hidden state, from the address book in the phone itself to the whole internet (which not 'in' the phone, but can appear on the screen and therefore appears to be part of it).

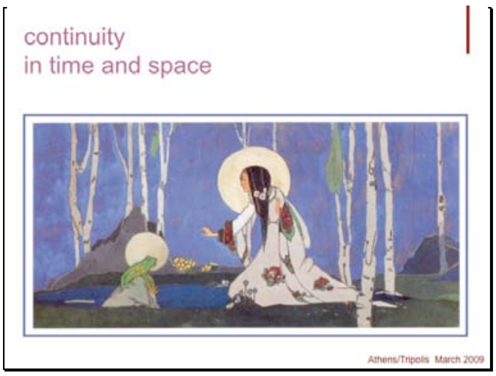
As noted it is not just digital technology that breaks these rules, the power of even the most basic technology is often in the way that it gives us super-natural power. For example, a simple saw means that a small amount of effort allows one to cut through a large piece of wood that would be impossible to break by hand (breaking directness of effort), and a bow and arrow allows action at a distance. Mechanical items like a car of course have very complex invisible state (look under the bonnet) and a chemical plant is very like digital technology in terms of complexity (open a valve one end of the plant and pressure goes up at a vessel at the other end.

It is interesting that in many areas of modern life where there is physical complexity, such as in the chemical plant, digital technology is being used to augment or substitute some of the unnatural activities. In a plane where cables once ran from cockpit to wing flaps, now wires carry signals to actuators. In the chemical plant not only are many valves operated electronically, but also sensors allow one to see the impact across the plant.

The last example is interesting as the sensors and visualisations in the chemical plant control plant allow visibility at a distance and reveal things inside vessels (pressure, flows) that one would not see by eye. The technology, by extending our senses, ameliorates the disorienting effect of the broken rules of physicality. In a way things distant and hidden become close and visible, so that the virtual world of the control room is closer to 'normal' physical reality than the situation a few years previously where the impact of actions was hidden or distant.

continuity in time and space – learning form fairytales

Most of the above rules are connected with some form of continuity. In scientific terms, digital computation is naturally discrete and discontinuous whereas physics (above the quantum level) tends to be about continuous processes. Indeed there is a special area of computer science Hybrid Systems focused on models that allow these two worlds to meet [[HY09]] and in my own work I have often looked at Status–Event analysis that tries to treat both kinds of phenomena on an equal footing [[Dx91, DA96,DL07]].



Continuity is often broken in magic worlds and in science fiction where portals and teleportation allows us to move across space, or in the case of the Tardis [[Ta09]] across time, without touching the points in between.

I have often found that fairytale, myth and science fiction are rich resources as they reveal which elements of reality are necessary to human understanding of the world [[Dx00,Dx09]]. If we examine theses stories we find that some parts of reality are bent or broken, like the portals or teleportation. However, if everything is broken we have chaos, and if we look more carefully we see that the story makers retain certain properties, suggesting these are more crucial to our internal models of the world. As designers this tells us what we should retain and what we can afford to lose in our own emulations of or interventions with physicality.

Take the story of the Frog Prince [[GG23]]. The princess eventually kisses the frog and it turns into a handsome prince. Although this transmutation is odd, we accept it in the magic world. However, imagine if the story had three frogs which when the last was kissed became a single prince. Somehow this is more shocking. Conservation of number seems more primitive than conservation of form.

In fact, this difference is borne out by studies of very young babies. New-borns cannot focus clearly, but as soon as a baby is able to focus it is possible to obtain a measure of interest or surprise by recording how long the baby stares at something before moving their eyes.

One experiment involves having a barrier and putting objects one by one behind the barrier. In the baseline condition, the experimenter puts one, two mice behind the barrier and then opens the barrier and the baby sees two mice. In other conditions the experimenter puts two mice behind the barrier, but when it drops there maybe three mice or just one mouse. In the conditions where the number revealed does not match the number put in, the baby will stare for longer, is more surprised … the tiniest babies can assess number (well at least up to 3!). In addition experiments with animals find a similar effect, that is many animals can assess number (not count).

An alternative test involves putting, say, a truck behind the barrier, but then when the barrier is removed, a duck is there. In such cases the babies show less surprise and need to be much older before they realise something is 'wrong'. In other words conservation of number is more primitive than conservation of form [[De97]]. The frog prince's transformation is not a surprise at all for a very young baby! This is of course very sensible for a developing baby: a single objects, such as a stick or a mother's face looks different from moment to moment as it moves, catches different light, or when the mother smiles. We have to learn over time which differences are simply ones of perspective and which really represent different things.

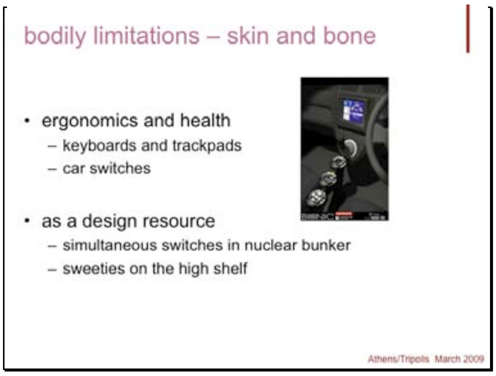
Physicality and the Body

bodily limitations – skin and bone

Our bodies are clearly physical things, skin and bone, muscle and tendon. Ergonomics was one of the foundation disciplines of human–computer interaction, although this is perhaps less evident in recent years were aesthetics of design have dominated.

I am an Apple user, and have used laptop computers as my principle machine for many years. However, I suffered terribly ever since the old curvy Powerbooks gave way to the silver 'Titanium' models and the more recent black and white MacBooks. The old curvy design had the 'mouse' button for the trackpad half over the front of the machine, so that you could use the trackpad with your index finger and click the button with your thumb. However, the more recent designs have the button flat just below the trackpad. To use this single-handed with finger and thumb means the thumb presses sideways, a very unnatural pressure, and the hand has to be held twisted.

In years to come will Apple find itself the defendant in class actions from all those Mac users with RSI? ... or will we all be too proud, after years of lording it over our Windows-bound colleagues, to admit that our Macs were less then perfect :-/



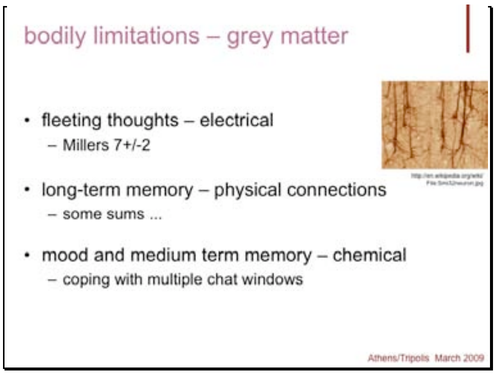
In other areas where digital and physical design interweave there is still a strong ergonomic influence, for example in car design, where it is recognised that the physical layout of the dashboard controls is as important as their appearance.

We of course have to worry about physical aspects in designing for accessibility. In the Hermes door displays mentioned earlier, it was very hard to place them so that they could be accessed while standing up, but also be accessible from a wheelchair. Bank ATMs, airport information systems and other forms of public displays have similar problems.

The physical limits of the human body can also be used as a design resource. In a nuclear bunker the buttons to launch and missile are deliberately placed far apart so that no individual can launch the missiles, but instead two people have to simultaneously press the buttons. A similar principle applies when we put sweeties on a high shelf to keep them out of reach of young children!

bodily limitations – grey matter

Our brains are also physical, apparently inert grey goo, yet full of electrical activity running through networked neurons and flooded with neurotransmitters.



If we consider memory we see the importance of all three forms of physicality: electrical, connectivity and chemical [[KV09]]:

- *short-term memory*. Our fleeting thoughts are carried electrically, as ionic discharges across synapses carry information from neuron to neuron, as is measured through EEG monitoring. This is the basis of all our immediate perception, and also short-term memory with its 7+/2 chunks of information [[Mi56]].
- *long-term memory* – In contrast, long term memory is assumed to stored in the physical connections between neurons and their strength. This storage literally grows, even the strength is determined by the size of the synapse. Based on the assumption that it is only this pattern of connectivity that matters, one can calculate the maximum information capacity of a single human brain - and it comes out at about half a peta-byte, about the same as the information capacity of the web … odd [[Dx05]].
- *mezzanine memory* - in between the short-term memory and long-term memory there are things between: the general sense of where I am and what I am doing and the memories of what I have been doing over recent minutes and hours that have not had time to 'grow' long-term memory and yet last longer than the effervescence of short-term electrical activity. This is less well studied in the psychological literature except for work in situation awareness [[En95]] and 'long term working memory' in studies of reading comprehension [[EK95]], indeed there is no name for this medium term memory, and the name '*mezzanine memory*' is my own. It seems likely that this form of memory is stored using chemical build-up with neurons, a process known as 'long term potentiation' [[Co00]].

Chemicals in the form of neurotransmitters also are constantly produced in our brains, and hormones flood through our bodies. Some of these chemical processes are quite fast, in the order of seconds, but some, especially these in our blood stream, may take many minutes to return to their normal state - think how long you feel 'jumpy' after a scare as adrenaline and other chemicals flood through your body and do not equally as fast disappear once you realise there is no danger.

Many of these relatively slow acting chemicals are critical to mood and emotion, and this has its impact on digital design.

Imagine visiting a friend who is about to have a party, then moving on to another who has lost a parent. We adapt and react differently to each, but in between our bodies have had time to 'reset' the chemicals that influence mood.

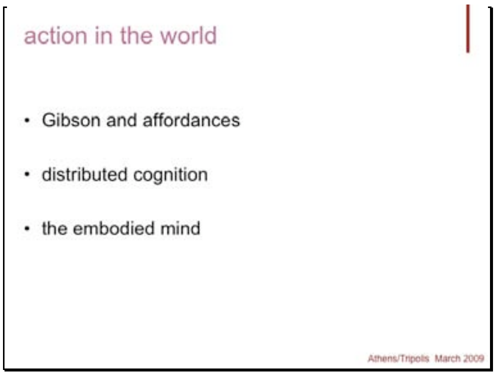
Now imagine the same scenario, but using instant messaging chat windows. On one side of the screen planning a party on the other a funeral. While the electrical parts of our brains may be able to rapidly adapt between situations, the chemical parts cannot.

action in the world

We are not purely cerebral creatures, but creatures designed to act in the physical world.

The concept of *affordances* is heavily used in HCI and comes originally from Gibson's theories of perception [[Gi79]]. For Gibson perception is an intimate part of our being acting beings. Suppose we encounter something in the natural world that happens to allow some action (or, in Gibson's terms. *affords* that action); perhaps a rock the right size to pick up. As our perception is tuned to the natural world then we do not need to reason "I see a rock so big, my hand is so big, therefore I can pick it up", but instead we will immediately perceive the action potential in the rock.

Of course we do not live our life in a fully natural world, but are surrounded by artefacts designed by people. On the one hand this means we will have learnt the action potential for many things that are not in the natural world, for example, the association between wall switches and lights. On the other hand, it not as obvious what the action potential of designed objects are unless they are *designed* to expose it to use through the way their shape mimics natural or learnt affordances.



As well as perception being intimately tied to the physical world, our cognition itself is expressed within the world. When we add up large numbers we use a piece of paper, when we solve a jigsaw puzzle we do not just stare and then put all the pieces in place but try them one by one. Some studying such phenomena talk about '*distributed cognition*' seeing our cognition and thinking as not just being in our head, but distributed between our heads, the world and often other people [[HH00, Hu95]]. Early studies looked at Micronesian sailors, navigating without modern instruments for hundreds of miles between tiny islands. They found that no single person held the whole navigation in their heads, but it was somehow worked out between them [[Hu83, Hu95]].

More radically still, some philosophers talk about our mind being *embodied*, not just in the sense of being physically embodied in our brain, but in the sense of being in our brains, bodies and the things we manipulate in order to do 'mind-like' things [[Cl98]].

If you think that is far fetched, imagine loosing your phone SIM card. Where are the boundaries of your social mind?

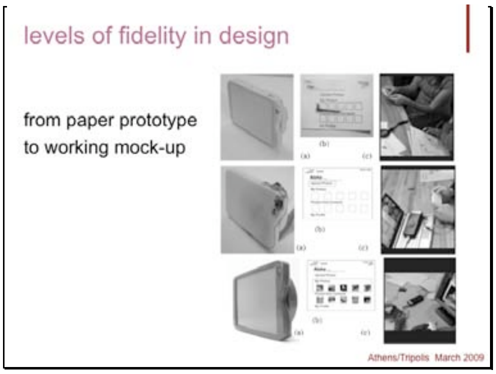
Physicality and Design

There are several ways in which physicality impacts product design:

- *during the design process* – How does physicality, the choice of materials, the tools used, the kinds of prototyping affect the way designers work and the kinds of things they produce. I won't expand on this here, but this issue was the focus of a paper from the DEPtH project in "Exploring Physicality in the Design Process." at the Design Research Society's 2008 conference [[RH08]].
- *during user testing and client demonstrations* – How does the kind of representation affect the way people perceive the product. Is it sufficient to see a paper prototype, or a screen-mockup, or is a fully working physical and digital prototype needed.
- *in the final product* – Understanding how people interact with and make sense of devices with both physical and digital aspects and how the digital form interacts with the digital functionality.

levels of fidelity in design

Traditionally product design has focused on physical form, from blue foam models and hand-moulded clay to 3D printers driven by CAD software. However, now they also need to consider the digital functionality behind the physical form. How realistic physically and digitally do prototypes need to be in order for them to do their job? In order to address this question, researchers at UWIC they have conducted a number of studies where several prototypes were produced of the same system, but at varying levels of physical and digital fidelity..



In one experiment they took a mobile phone design and experimented to see how much the results of user testing would change as the prototype varied form a fully digital on-screen prototype to the actual fully functioning phone itself [[GL08]]. The experiment made use of custom hardware the IE unit which takes button presses and other physical inputs and converts them into character streams, as if from a keyboard, that can be used to drive Flash simulations.

The most 'realistic' prototype consisted of taking the actual phone body, but instead of having the display in the phone, the display was instead reproduced on a second monitor screen to emulate a high-fidelity prototype before final hardware integration. Surprisingly, despite the eyes-up/eyes-down difference between it and a normal phone, there was surprisingly little difference between this and the real phone. Replacing the real phone hardware with a foam body and a moving keypad also made little difference. However, when a flat membrane replaced the keypad, then new errors and problems emerged.

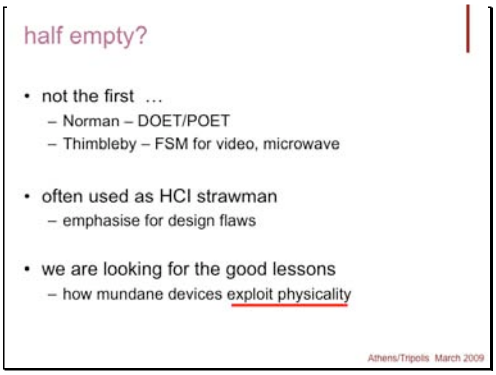
study the old to design the new

Another approach is to examine existing everyday appliances and to try to understand how designers have leveraged their users understanding of physical form and action [[GD03, GD05, DG09]]. Sometimes the designers may explicitly do this, but often their knowledge will be tacit, yet expressed in the actual designs they produced.

Appliances studied include simple light switches, washing machines and mini-disk players (although these now seem a little dated!). As well as being the result of expert design processes, many of these designs have been 'tested' by the marketplace. This does not mean they use physicality perfectly, but certainly they must be doing something right! We are attempting to mine this tacit knowledge embodied within these designs and make it explicit.

half empty?

There is a long tradition of studying ordinary designs in HCI, not least the humble light switch. For example Norman in "The Design/Psychology of Every Day Things" [[No88,No90]] looks at nature of mappings between controls and their effects and Thimbleby has used Finite State Machines to study the functionality of VCRs and other appliances [[Th07]].



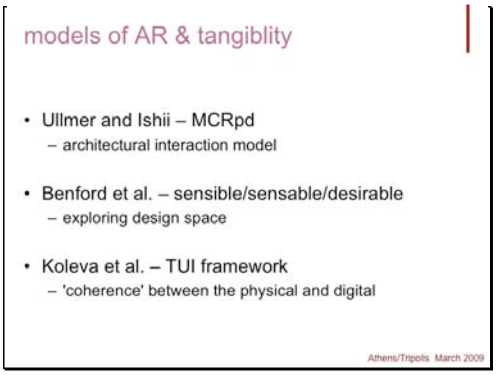
However, most often these appliances are used as strawmen, where the their design flaws in the device are highlighted through war stories and anecdotes, and then it is shown how good interaction design could have made them better. That is, how ordinary designers can learn from HCI theory.

In our own approach, we have instead focused on positive ways in which these mundane devices exploit physicality. That is, how *we* can learn from them.

models of AR & tangiblity

A number of formal models and frameworks have been developed to understand the construction and design of tangible user interfaces and augmented reality. This is reviewed in more detail in [[DG09]].

Ullmer and Ishii's MCRpd/MCRit [[UI01]] is an architectural interaction model, at the same sort of level as MVC or PAC models, but instead focused on tangible interactions, and the same group have more recently looked at the use constraints for modelling/implementing these systems [[UI05]].



Looking more towards design issues, Koleva et al. [[KB03]]created a framework for analysing tangible interactions along a number of dimensions trying to understand different levels of 'coherence' between the physical and digital. Focusing on ubiquitous device design and augmented reality, Benford et al [[BS03, BS05]] developed the sensible/expected–sensible–desirable framework to help designers explore the design space of novel devices, this looks at the user's intuition (*sensible* or *expected* things the user might do with the device), the devices capabilities(what is *sensible* as in what the various sensors on the device can measure), and at the underling functionality/semantics (what is '*desirable*').

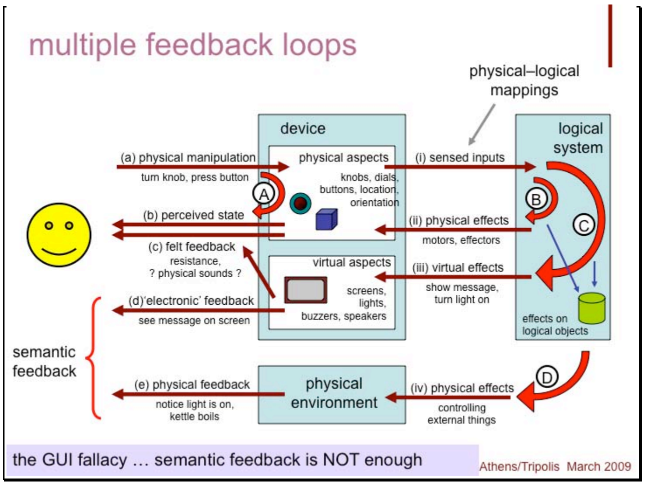
multiple feedback loops

Imagine you are about to make a call on a mobile phone and start to enter the number. You will experience several different forms of feedback:

- you feel the key being pressed
- you hear a simulated key click sound
- the number appears on the screen

Note that the first of these is connected purely with the physical device you still feel it even of the battery is removed; the second is a sort of simulated real sound, trying to be as if the physical keys made a noise; and the last is purely digital.

We have used the following diagram (described in more detail in [[DG09]]), to understand these different interaction paths, with the forms of feedback in the above corresponding to loops (A), (B) and (C) respectively. The final loop (D) corresponds to systems where there is some ultimate physical effect, such as the water boiling because you put the kettle on. Interaction Frogger [[WD04]] uses a similar model in order suggest design strategies for more effective feedback (what has happened) and feedforward (what will/could happen).



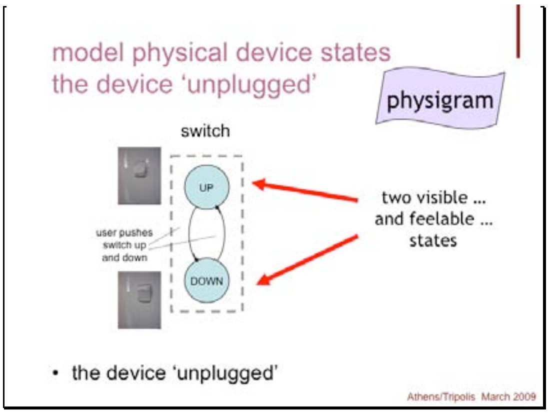
GUIs and in particular the direct manipulation paradigm tend to focus on the semantic on-screen feedback (C). They attempt to produce the illusion that the screen is the real world of the user. This has been very powerful, but breaks down in certain situations, for example, where there is a delay in semantic feedback and some form of immediate "yes you have done it" feedback is also required [[Dx94]]. The focus on semantic feedback is deeply built into the MVC model and also in Seeheim. Although the latter (largely pre-GUI) also recognised the need for a more direct 'fast path' for feedback as those who defined the model realised that the deeper semantic paths was not always quick enough.

The normal over-reliance on loop (C) in interaction design can be thought of as the *GUI fallacy*, but often semantic feedback is NOT enough.

One example of this is multi-tap on mobile phones. These typically show a small display with the currently selected character (loop C), but it seems only the utmost novice looks at this. With my own phone I have noticed that I often do 4 taps when I meant to do 3, for example getting a '2' instead of a 'c'. It took me a while to realise this was because of interference between the immediate physical feedback (A) and the simulated key sound (B). If I turned the phone to silent which suppressed the latter, my multi-tap accuracy improves (sorry no empirical data just personal anecdote!). I think the reason is that there is a slight delay (no more than a fraction of a second) between pressing the key and the sound. I am mentally counting the taps, but by the time I hear the third tap I have already pressed one more time. It is interesting that the aural feedback dominates the physical feedback (A), which is more accurate.

model physical device states

We have been looking particularly at loop (A), the direct physical feedback due to the device. We effectively consider the device 'unplugged"; as in the phone without its battery, or a light switch torn from the wall. Even with no connection to its digital/electronic actions, still the device has interaction capability. You can press the functionless keys, or idly flick the disconnected switch.



As part of this we have used augmented finite state diagrams to model these purely physical interactions. The switch here has an associated two state diagram "UP" and "DOWN" as these are physical states of the switch itself, with particular user actions (pressing up or down) causing the physical switch to change.

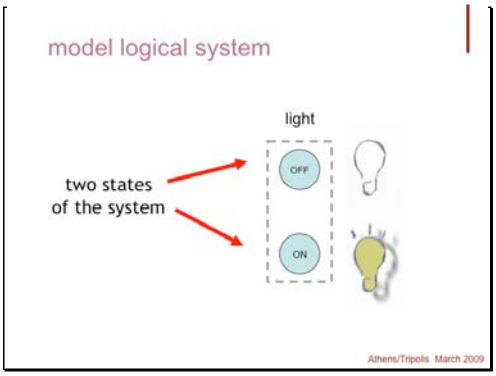
We call these diagrams of the device unplugged, *physigrams*.

Finite state diagrams were chosen, as they are a common and simple representation. However, we are aware that are not sufficient to model the subtlety of physical interactions, but they. So, we add various annotations/decorations (different shaped arrows etc.) to try to capture some of the more subtle aspects such as he way when you start to press a button it usually 'gives' a little before it fully goes down.

model logical system

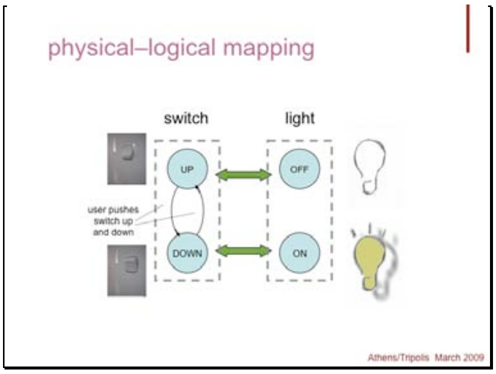
Of course we are also interested in the 'logical system', the digital or electronic aspects of the device, and the way the logical system interacts with the physical aspects of the device. So we also, more conventionally, produce a finite state description of this.

In the case of a light this is particularly simple, just two states: "ON" and "OFF".



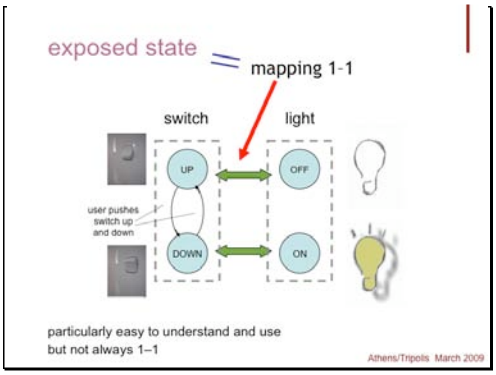
physical–logical mapping

The two models, physical and logical can then be linked and we can then use the properties of the models on their own and the mapping between them as a tool for analysis and design.



exposed state

The light switch is particularly simple as there is a one-to-one mapping between the state of the physical system (switch up/down) and that of the light's state (on/off) - albeit which connects to which is somewhat cultural!



Note that it is possible to know the state of the light from the switch alone, and also, perhaps more critically, you can tell that you did something. If, for example, the lights are neon and there is a delay, then this becomes critical. With switches that work by touching or pressing only, it is easy to touch a switch, notice there is no response and then touch again thinking your initial action has not registered. Of course the second press often cancels the first!

We use the term *exposed state* for the cases where some or all of the logical state is apparent in the physical device, and these are particularly easy to understand and use.

Of course not all mappings can be 1–1 as this would limit us to systems no more complex than our physical devices, and so we have also used these methods to study other classes of systems and the interaction techniques that work well with different kinds of physical-logical connections.

One example is the *natural inverse* [[GD03, GD06]] where our natural 'opposite' reaction can be used as a form of automatic 'undo'. If you are reversing a car and are not very expert, you may have to think consciously or experiment to get the right initial direction to turn the wheel. However, once you are moving, if you overshoot and turn too much, without thinking you simply turn the wheel the other way. In this case the semantic mapping (which way to turn the wheel to get the right car movement) is not understood, but the physical mapping obeys the natural inverse (opposite movements have opposite effects), so correction is natural..

Not all devices satisfy this natural inverse property and it often causes problems – how many times have you tried to get a toaster to pop up by pulling up in the handle?

We have been conducting some experiment where we deliberately manipulate these physical and semantic mappings to investigate how they cause different kinds of errors (early experiments reported in [[GD06]] and some ongoing).

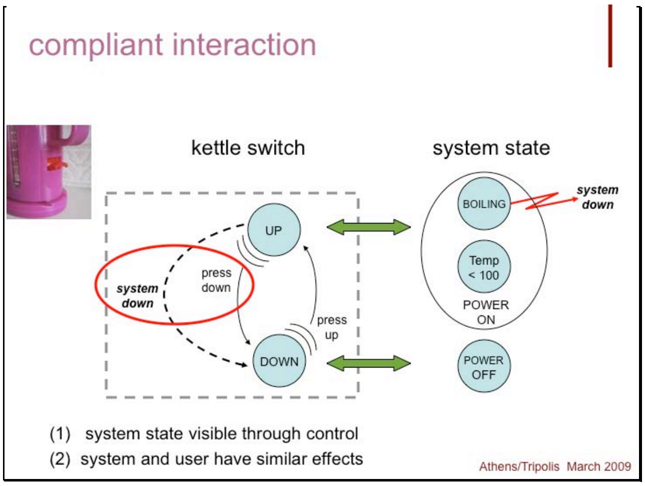
controlled state

In the case of the light switch the control of the switch lies entirely with the user. There may be logical/semantic effects that the user does not directly control (e.g. the light fails, or a timer turns it out), but the light does not affect the switch itself.

However, in some devices the physical control may be changed by the system also - as in toaster handle that pops up when the toast is done (or maybe burnt), electric kettles that switch off when boiling, or a traditional washing machine dial that click round through its programs.

compliant interaction

The kettle and the washing machine have a particularly interesting kind of controlled state in that the way they change the control device is nearly the same as the way the user does. In the case of the kettle if you want to switch off the kettle before it boils you flick the switch, and when the kettle boils it turns off the switch in exactly the same way.



We have used the term '*compliant interaction'* to describe this kind of parity between user and system control.

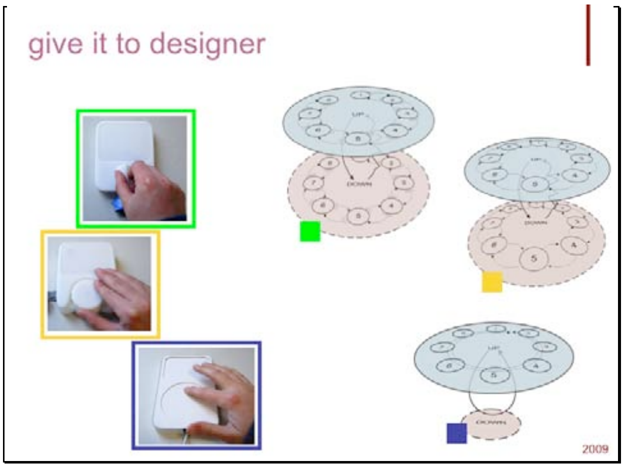
In the case of the washing machine the fact that the system state is exposed through the control leads to incidental learning and expert washing machine users (who even in our world of sexual equality are typically mothers) can do things like 'skip to the rinse cycle'

Note that not every aspect of the device will be available equally to user and system. For example, you cannot magically wash the clothes by spinning on the dial! However, users seem to be able to grasp the difference between the possible and the impossible and only get confused or frustrated when what seems as if it should be possible does not work – as in that toaster handle!

give it to designer

Finite state diagrams are all very well for computer scientists, but what about real product designers?

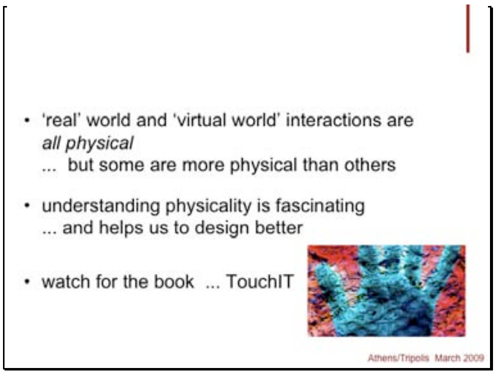
The team at UWIC were already engaged in a mini-project looking at alternative designs for a photo-browsing device that differed in the details of their physical interactions (now reported in [[HG09]]). So they took the existing examples of diagrams for light switches, kettles etc. and used them on this real design exercise.



They had three device designs all with the same overall shape, a screen with a rotary control below it used to make menu selections. One used a knob with a number of fixed 'stops', one had a rotary dial, but with no markings. It could spin arbitrarily, but you could just feel it 'bump' over selections. The last had a smooth round track-pad style control, rather like a recent iPod (rather than the original physical dial ones).

The physigrams produced by the designers showed both the similarities and differences between the designs and also we found that the desigers augmented the basic physigrams in new ways indicating the importance of keeping notations 'open' [[DG09]].

Summary



Both 'real' world and 'virtual world' interactions are physical in that we interact through physical means and the underlying computation is physical. However, some interactions are more physical than others: for example, swinging a Wii compared with typing on a keyboard.

Even if it had no use whatsoever, understanding physicality is fascinating, At a philosophical level what is the fundamental nature of the physical world and our embodiment within it; and at a psychological level, how do humans make sense of and make use of the physical properties of things around them..

However, this theoretical understanding is also intensely practical and helps us to design better.

Finally, watch for the book TouchIT – we promised a 'coffee table' book as a deliverable for the DEPtH project, so it will come soon!

Acknowledgements

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I would also like to thank the participants at the Swiss Universities' Winter School in Anzere, the Winter School for "Interactive Technologies for the End-User", in Bangalore, the Greek SIGCHI Workshop "Human-Computer Interaction: Theory and Practice of design of usable and accessible technologies" in Athens and students and staff at the University of Peloponnese, Tripolis.

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