Making Ritual Machines: The Mobile Phone as a Networked Material for Research Products

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ABSTRACT
Viewing the mobile telephone as a networked material, we demonstrate the ways in which we have used it to make Research Products for the 'Family Rituals 2.0' inquiry of families separated by work. Drawing from a diversity of sources we survey and deconstruct the phone as a material that can be worked to a vast range of technical effects, extended by hardware and configured by software. We demonstrate the transformations of hacking and prototyping practices necessary to construct complex Research Products through the case study of our machines. We offer the Interaction Design community seven specific and actionable techniques for using mobile telephones in Research Products. Finally, we open up a broader discussion for researchers and practitioners using mobile phones as a design material in their work.

Author Keywords
Prototype; Research Product; Mobile Telephone; Tangible

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Changing patterns of work-related mobility and domestic arrangements mean that *mobile workers* face socio-technical challenges for supporting and engaging in family life whilst travelling for work. This was the subject of our inquiry in the recent project Family Rituals 2.0.

Through a Research through Design (RtD) approach [20] and a critical technical practice [1], we have developed bespoke Ritual Machines for five real families who experience separation from home due to work, as material explorations of their lives and practices. This incorporated phases of design ethnography [42,2], the use of Cultural Probes [22], prototyping and Technology Probes [26]. Our machines are playful, provocative and perturbing. They are not solutions to any *problem* of absence from home per se, but rather a way of soliciting further reflection providing a situated *ticket to talk* about families' attitudes to home and work, the ritualized activities that constitute *being a family* and the concomitant role of technology [30]. Each family typically lived with a machine for a period of one month.

Our focus on *ritual* [9] as an activity within domestic arrangements brought to the fore a variety of artifacts and the tacit practices around them. Previous work demonstrates the value of tangible objects to the structuration of ritual activities in the home [40] and this, alongside extant work on the communicative value of *phatic technologies* for domestic settings [23,24], led us to develop and deploy *smart networked things*.

Designing for spaces like the home, truly in the wild, and for bespoke artifacts that must interweave with enduring practices of domestic routine, over extended periods of time, behooves the development of Technology Probes with a certain stability and fit with their environment. With this in mind, we have been drawn to the articulation of the *Research Product*, as recently given by Odom et al. [38] which emphasizes the *finish*, *fit* and *independence* of the artifact.

As a small team with limited time and budget, our pragmatic focus was on the resources we could draw upon to produce and deploy a series of highly finished bespoke Research Products. Our Family Rituals' probes and machines are assemblages of found technologies, third-party modules and bespoke electronics, combined in ways most familiar to practices of prototyping and hacking. Across all five of our engagements, the modern mobile phone featured significantly as a design material, inexpensively providing a plethora of diverse technical features to be combined in software in potentially complex ways.

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In this paper we aim to contribute to the emerging discourse around Research Products, through the provision of a detailed description of our design process in the Family Rituals project. In particular, we share strategies for the *use of mobile phones as a design material* for those engaged in design research projects, especially those working with *smart things* [31]. Detailed accounts of these Family Rituals engagements are published elsewhere [30] and will be forthcoming.

Our paper is split into five sections. First we consider the tensions between hacking, prototyping and Research Products. Second, we analyze the modern mobile phone as a resource and networked material, including a review of ways it can be worked to different technical effects. Third, for our Cultural Probes and each of the five Family Rituals' machines, we show and reflect upon how the phone was transformed to offer the qualities needed in Research Products. Fourth, we offer seven generalizable techniques. Fifth, our closing sections offer reflections on this process for researchers and practitioners.

HACKING, PROTOTYPING AND RESEARCH PRODUCTS

In this section we consider the practices of hacking and prototyping, and how they are integrated with and different from the production of the Research Product [38] in a Research through Design inquiry [20].

The hacking and adaptation of existing hardware and software have long been essential activities in communicating and exploring future propositions through prototypes and in the production of ad hoc solutions.

The rise of the so-called Maker Movement is scaffolded by a set of readily adaptable and affordable tools (such as laser cutting and 3D printing) and modules (notably the Arduino and Raspberry Pi). Frequently these activities are made communal in Hacker and Maker Spaces. These *open* tools and practices continue to permeate academia, start-up and corporate industrial design. Lindtner et al. [33] discuss this in specific reference to innovation in tangible and ubiquitous computing, from hacks to product propositions.

Beyond their instrumental use in Research & Development, *prototypes* are a material output of Research through Design approaches in practice-based research. Arrigoni et al. [7, p.9] remind us that they, *"are becoming relevant not just as a step of development in product manufacturing, but as something endowed with intrinsic value both as an artistic medium and a research process."* Odom et al. [38] offers us a comprehensive discussion of the role and nature of prototyping within HCI research.

Turning to specific techniques for hacking and repurposing found devices, Petrelli et al. [39] introduce three productive ways to create fast Tangible Computing concept prototypes. They identify three modes of hacking: *embedding*, *cracking it open* and *collating*. They emphasize the rapid development of physical prototypes in combination with digital fabrication techniques, where behavior is largely derived from simple adaptations of the found device; for instance a voice recorder. this makes the original selection of the device very important.

We have engaged with Research Products [38] retrospectively. Throughout the development of our machines we struggled to find a vocabulary to describe our necessary concerns in designing and building complex systems working independently in a complex world over a sustained period of time. We felt that our development and use of the machines went beyond a common use of *prototype*, with its connotations of fragility and there being a *moment* of *demonstration*. Odom et al.'s articulation of *Research Products* gave us the vocabulary we were seeking and a framework to productively apply.

We now offer some points of reflection, comparison and critique on the qualities of Research Products (*inquiry driven*, *finish*, *independence* and *fit*) as suggested by Odom et al. [ibid].

With regard to *inquiry driven*, our machines were designed as a critical inquiry of the present, rather than being *"designed to ask particular research questions about potential alternative futures"* [38, p.2551]. We find this future orientation somewhat problematic and at odds with a focus on the artifact's evident reality. Similarly, our designs did not consciously *embody theoretical stances* or an explicit hypothesis. Yet in broader terms they clearly were *inquiry driven* with regards to families experiencing work-related separation.

The *finish* of our machines communicates that they are to all intents and purposes real and consequential, not provisional. It speaks of our effort and commitment. Finish goes beyond a surface level reading; it is present in both the physical materials and the electronic behavior of the artifact. Finish elevates the fragile hack and is not achieved in haste. Finish builds *independence* from our intervention; distinguishing it from the context-defined prototypes and demonstrations. We hoped that these machines would develop rituals over long periods of time, so they had to work more or less independently.

Through our engagements with the families and resulting bespoke machines, we are deliberately attempting to manipulate the *fit* into their lives and their environments, be that familiar or strange. We have previously written about *making technology at home* [30]. However, we do not argue that the fit must be individually bespoke; batch produced multiples, such as the Datacatcher [21], might also be considered as a Research Product. Arguably, levels of both finish and fit should not simply determine whether something is, or is not, a Research Product, when manipulation of those qualities themselves might directly relate to the research questions being addressed.

Our machines are 'one-offs', produced largely in-house within the constraints of limited budgets, time, equipment, skills and labor. The complex technical effects we produced result from assemblages of found technologies, third-party modules and bespoke electronics; configured by techniques drawn from hacking and prototyping, yet exhibiting the properties of Research Products. Significantly, in all our machines, the mobile telephone is exploited as a readily available, complex and configurable material. In contrast to Petrelli et al.'s [39] found function, this flexibility offers a complexity of outcome, necessarily being produced relatively slowly and deliberately.

We acknowledge that for specific telephony functions it is evidently possible to specify and build hardware without hacking an existing device and that this approach offers a level of finish and control that we cannot otherwise expect to meet [21,36]. Additionally, that this is highly suitable for batch manufacture. However, as we shall discuss, the modern mobile phone offers an abundance of technologies that we can reconfigure at little cost in software as part of a small scale exploratory Research through Design project.

Our contribution is to demonstrate transformations of hacking and prototyping practices in the production of Research Products with the required *finish* and consequential *independence*. We offer seven techniques addressing how the mobile phone can be worked as a networked material to this outcome.

THE MOBILE PHONE AS A RESOURCE

The mobile telephone is a modern phenomenon, the product of global supply chains, agreements and infrastructures, incorporating the intellectual and physical work of millions of people. With a global demand, the cost of these extraordinary devices has been driven below any reasonable expectation. We have recently purchased a new Android telephone in Walmart (USA) for $5, complete with touch screen, compass, accelerometer and GPS. Low-end smartphones are now regularly available in the UK for $50 or less. Secondhand, repaired [25] and discarded devices further add to this availability.

We should not approach the availability of the mobile telephone uncritically. These devices exploit human labor and natural resources at a global scale. We must acknowledge our privilege. Initiatives such as Fairphone (fairphone.com) draw our attention to these issues.

An attempt to enumerate the technologies available in the modern mobile telephone would include: microphone, speaker, telephony (to make and answer calls), SMS and MMS messaging, Internet connectivity (mobile data or WiFi), backlight colour graphical display, touch (frequently multi-touch) input, camera (often front and rear facing), fingerprint reader, GPS receiver, magnetometer (compass), accelerometer, gyroscope, altimeter, barometer, thermometer, Bluetooth, NFC (read and write), FM radio, multimedia playback, storage (including SD card), processing, rechargeable battery, vibration motor and a bright light. Significantly all these technologies are configurable by software to complex effect.

The current dominance of the Android and iOS platforms, their associated tools and APIs vastly simplifies the task of deploying software on innumerable devices. By *rooting* these devices we gain deeper access to normally privileged commands; the legal status of this varies internationally.

These inexpensive and highly featured devices are therefore very attractive as a resource for building prototypes and Research Products, where software affords reconfiguration and experimentation at a far lower cost than bespoke hardware. This is an approach we used extensively throughout the Family Rituals project.

THE MOBILE PHONE AS A NETWORKED MATERIAL

We find it productive to consider the mobile phone, a collection of diverse technologies with a small and typically uncomplicated form, as a complex material with properties we can work to many technical effects. Further, we conceptualize it as a networked material that is inherently entangled with the complexity of the world. This is in the tradition of Martinussen and Arnall's [34] analysis of RFID as a material for design. Ingold has a body of work (notably [28]) that argues for the proper consideration of *materials and their properties* over notions of materiality and material culture [37] that draw our attentions towards abstract concepts and philosophy. Materials, Ingold contends, are too often left underexplored in inquiry. Responding to Ingold's provocation, we pull focus herein on the core material features of the mobile phone; these are relatively fixed with certain affordances that must be worked with in the design process.

To support our contention that the mobile phone is a material to be worked, we now give exemplars that exploit the constituent technologies in material ways. We draw these from a set of otherwise diverse sources; significantly many come from the hacking and making communities. It is clearly not an exhaustive survey. We shall later show how some were applied in the Family Rituals project.

Telephony

Telephony has been used in a number of interesting ways, often in combination with an Interactive Voice Response (IVR) service hosted on the telephone network and available by dialing a specific number. Callers can interact with their voice and by pressing numbers on their keypad. This is attractive as it requires no software to be installed on the telephone itself and so can be used with any generation of device. Crivellaro [17] demonstrates this for engaging local communities in aural discourses on change. Here a handset is housed in a suitcase and keypad buttons are labeled appropriately on a fascia, which obscures unused functions. RootIO [18] hosts a radio station as IVR on an Android device for contributors to call into to; it is connected to a transmitter, battery and solar panel.

Audio

Beyond recording and playback there are a number of techniques for appropriating the telephone's audio features.

The 3.5mm jack socket provides a near universal way to attach speakers or headphones. Increasingly now with the introduction of headphones with an on-cord microphone this is a TRRS (Tip-Ring-Ring-Sleeve) jack. While there is no standard, iOS devices and most Android phones share the same wiring. The additional microphone line also allows simple signaling for play/pause and volume. Since iOS 5.0 and Android 4.3, the volume button has been enabled as a convenient physical camera trigger. Combining these innovations leads us to the Selfie Stick! This enables simply implemented external button inputs. However, this is set to change with Apple's recent high profile rejection of the 3.5mm jack in the iPhone 7.

The Square Reader (squareup.com/reader) is a commercial credit card reader that uses an external circuit to read the magnetic stripe in via the microphone input. The Maker community has also developed several ways to encode instructions in audio signals, for instance Terasaki's Smartphone Servo [46] directly controls up to two servo motors from the stereo jack; an external battery is required. Disney's Acoustruments [32] constructs an ultrasonic pathway, a physical pipe, between the speaker and microphone; the audio properties of which are changed during interaction. A variety of path designs allow rotations, pressure and orientation to be sensed.

Display

The typically color backlit display affords several adaptations. Simplest of all, it can be framed, breaking up the given rectangular form. Luckybite's BirdBox alarm clock [13] does this, making a window through which we see the time or footage from a nesting box. The Palm Top Theater [35] uses three parallel half-silvered mirrors held at 45 degrees to the screen, to create a multi-depth display. Google Cardboard [15] constructs a cardboard frame that extends the display with stereo lens and allows it to worn against the face. Randle's Shepherd [43] uses light sensors attached to the display, selectively illuminated by onscreen graphics, to trigger an external circuit.

Multi-touch

The modern multi-touch sensor can be exploited in a number of ways, depending on the underlying technology; typically either capacitive (electrical) or resistive (pressure). Befurt's Auto Tinder Swipper [8] generates a faux swipe gesture on capacitive devices; an electrically grounded stylus is moved across the surface of the screen with a servomotor. Randle's Shepherd [43] makes four faux touches in four fixed positions using a similar technique. In this way an external circuit can manipulate UI elements made available in software.

There are a number of approaches giving objects interactive qualities when placed on screen. Typically for capacitive multi-touch, conductive materials electrically extend the touch from the fingers through the object onto the screen; for instance Aeschlimann's Little Boxes [2]. Disney's AppMATes (appmatestoys.com), uses this with an identifiable configuration of pads in contact with the screen to recognize a specific toy car. In addition, light pipes in the toy channel illumination from the screen to allow the car's headlights to be operated.

Magnetometer

While typically used as a compass for location based applications, the magnetometer has many wider uses detecting changes in the local electromagnetic field. A set of interactions have been shown with passive magnet based approaches. The first version of Google Cardboard [16] used the changing position of a strong neodymium magnet as a button and could be sited on the exterior of the case. A range of familiar controllers (sliders, buttons, knobs, etc.) were enabled in this way by Hwang et al. [27]. Bianchi [12] demonstrated a series of interactions based on a tangible's position and orientation with respect to the phone. Bennett's Resonant Bits [11] show the gestural potential of such tangibles in bespoke physical forms. Active circuits to manipulate the phone's electromagnetic field have also been shown. Desbonnet's Poor Man's NFC [19] actives a small coil to send data, albeit slowly. Finally, Sturgeon and Ray [45] used the magnetometer to sense the electric fields of local appliances.

Computation

Even low-end mobile devices offer considerable computational resources that can be operationalized by other systems. Typically, these might be connected by USB or Bluetooth, using software on the phone to orchestrate behaviour between external sensors and actuators. For Android development boards such as Sparkfun's IOIO are attractive, connected and powered by USB OTG (On the Go) or by Bluetooth Low Energy with an external battery. Apple restricts the development of hardware accessories for iOS and Bluetooth is the most available option. Coupled with software development tools that assume little experience of programming computation becomes a ready resource.

Network

The ability of these devices to react to and initiate action over distant networks is widely exploited. To take one example, the Rainforest Connection project [49] uses the surprising levels of GSM connectivity in the forest to create a network of modified mobile phones running software to detect the characteristic sounds of chainsaws; giving a real-time alert for illegal logging. The units have a weatherproof enclosure and are adapted for solar power.

Camera

Various optical adaptations can be made to the camera. Most apparently there are a range of external lens that can be fitted, some giving a microscopic or fisheye view, others creating novelty filters. Public Lab's fluorescence spectrometry [48] goes beyond this; using an ad hoc prism, made from a CD, to identify a range of environment contaminants in the wake of the 2010 BP oil disaster.

MAKING RITUAL MACHINES WITH MOBILE PHONES

Below we describe the use of mobile phones in the design of our Family Rituals' engagements, both for the Cultural Probes and five Ritual Machines (our Research Products); transforming the exploits we have previously identified.

Cultural Probes - Digital Question Box

Our initial engagements with the families were framed around interviews and Cultural Probe [22] packs. Each pack contained a playful collection of diverse printed and object-based activities that, when completed, would provide us a glimpse of their domestic life and everyday rituals. A detailed description of our packs can be found in [30].

Our Cultural Probes included a Digital Question Box (Figure 1) that asked timely questions on a small screen, for instance *"How did you take a break today?"* The family responded by writing an answer on paper that was posted into a slot in the box, which was used in the next interview as material to structure the conversation. The answers tended to be given spontaneously and quite casually. No other interactions with the device were available.

The design of this Cultural Probe was based on an inexpensive Android mobile telephone with a custom app. Questions were displayed at different times of the day, each for a finite time, typically an hour. We developed a series of laser-cut cardboard phone housings, (after Petrelli [39], *embedding*). We explored birdhouse shapes (inspired in part by the Luckybite BirdBox [13]) and devices that contained a mechanical shutter to reveal a new question; intended to create a moment of occasion.

Written as a replacement lock-screen, the app is always shown. Messages were either delivered in real-time from us by SMS or scheduled from a file. In later versions an SMS microformat specified the duration of display. Using SMS required no on-site configuration to be made on delivery.

The construction of the box framed the screen and gave access to the power button (with a pencil inserted) and to the USB charging port; specific to the embedded phone. Typically they were permanently plugged in and always on.

The mechanical shutter was driven by a servomotor and an Adafruit Trinket microcontroller. It triggered on the appearance of a white dot on screen, read by a LDR sensor (as Randle [43]). For power the Trinket was wired in parallel to the telephone's USB connection.

The embedded phone exploited *the network* and *display.*

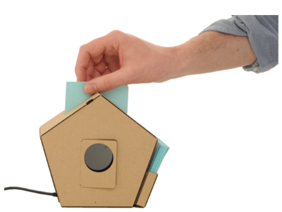

Figure 1: Digital Question Box

Machine 1 - Drinking Together Whilst Apart

Drinking Together Whilst Apart (Figure 2) is a machine that pours a glass of wine in synchrony with a beer bottle-opener being used. A Bluetooth-enabled bottle opener connects to an iPhone and a WiFi wine machine. It was designed for participants Craig and Holly to live with. They enjoy a drink together at the end of the day when they've done *"all the serious stuff"* and this machine questions whether this ritual could be meaningfully extended when they are separated. We intended for the wine machine to be installed at home, with the bottle-opener being taken with Craig, the travelling partner. (See [30] for a full description of the design process and associated ethnographic study).

The wine dispenser contains a WiFi connected Arduino Yun controlling a high-torque servomotor that mechanically operates an unmodified wine optic. Sensors detect the glass and LEDs cause it to be illuminated when inserted.

The design of the bottle-opener posed several important challenges. Firstly it operated mechanically to remove bottle-tops. Secondly it was able to sense and communicate this event across the Internet in real-time. Thirdly it presented no problems for Craig in the likely circumstance that it would be taken through airport security, or similar.

A musical bottle-opener was used as donor for the *teeth* of the device, which also provided a convenient sensor - based on the conductance of a metal bottle-top. We opted to use an app on Craig's own iPhone as a means of making the Internet connection (across any available network) and to be a point of interaction. A Bluetooth 4.0 module provided the local communication between the bottle-opener and the telephone. The circuit was powered with a watch battery and had a power switch, described as a flight-mode. The components were fitted on a custom PCB, enclosed in a laser-cut acrylic case, intended to publically convey a professional (perhaps mass-manufactured) finish.

When a glass is placed in the machine a notification is sent to the iPhone using the Apple Push Notification Service [4], stating "Glass Inserted" and optionally opening the app. The app shows the state of the machine at any given moment, whether the bottle installed or the glass is present (and whether it full or empty) and whether the opener is connected.

The phone is primarily used as means of providing *computation* and *networking*.

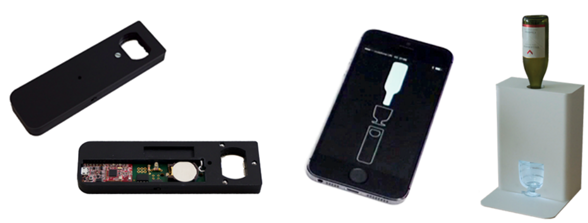

Figure 2: Drinking Together Whilst Apart

Machine 2 - Anticipation of Time Together

Anticipation of Time Together (Figure 3) counts down to a family event; a mechanical flip-dot display shows the passing time through an animation reminiscent of a sand timer. It is designed as a piece of furniture, standing at just under one meter tall. See [30] for a full description of the design process and associated ethnographic study.

This machine was designed for Hywel and Jesper, reflecting their love of travel and frequent separation. Whilst apart they could see the display of the machine through an app we designed for their personal iPhones. In addition, they could communicate touches through the screen that were displayed in real-time. However, to set the time that they were anticipating, they needed to be together in front of the display. Through this interaction, we sought to structure a small ritual and enjoyed the Cold War film language of double locks and secure systems requiring two people to initiate a sequence. Further the interaction spanned the two screens, so that they would be moved together to complete the display.

The display uses two commercially available flip-dot modules under the control of a Raspberry Pi 2, which uses WiFi to connect to the Internet. The proximate interactions with the iPhones are achieved through a Bluetooth 4.0 dongle that advertises an Apple iBeacon [5] around the display and allows each iPhone to report their distance to it.

The two phones are exploited as point of interaction and remote view of the machine, across the *network*. When proximate, there is a local cooperative behaviour using their identical forms, treating it as a continuous display.

Figure 3: Anticipation of Time Together

Machine 3 - Connecting Through Housework

Connecting Through Housework (Figure 4) is a robotic vacuum cleaner that operates at home only when a mobile totem device, carried remotely, moves at speed. The robot's behavior reflects the routines of the distant family member.

This machine was designed for David, Irene and their two teenage children: Rikard and Rebecca. David works away from home for prolonged periods in a different county to his family. During our interviews, the children made the joke that they miss their Dad when he's away, because they have to do more of the chores at home.

The machine was designed such that when David was away, the robot would mirror his routine, moving silently when he was walking, and starting to clean at higher speeds when he was using some form of transportation. Returning to his *work-home* at the end of each day, the vacuum would seek its recharging station. It would expose David's routine movements whilst contributing to housework in his absence.

David's totem contains an Android mobile telephone running a custom app that measures his speed by GPS and communicates this across the Internet to the vacuum. The vacuum is a modified Roomba 650 (irobot.com) controlled by an Arduino Yun connected to the home WiFi network, using the iRobot Serial Interface [29] to control behavior.

Touching the totem display causes the light on the robot to be instantaneously momentarily brighter; giving it a shake causes the robot to make a rotating action. Tapping the robot causes it to stop. This is acknowledged on the mobile device by playing a knock sound vibrating and changing the display. This notification is sent by an Internet/SMS gateway; proving a convenient means to address the phone in real-time.

Both the robot and totem have a similar single light display and a shared color language. This communicates a low battery (red flashing) or the loss of a data connection (blue flashing). Static colors are a representation of David's location calculated from the HSV color wheel, where the compass bearing to home determines the hue; and the distance from home the saturation. In this way different places have recognizably different colors, without revealing a precise location. Additionally, David's totem reflects his speed by animating the light along a Lissajous figure.

The Android phone is enclosed in a wooden case, through a circular window a portion of the display is visible and touch interactions can be made. There is a hole for USB charging and the power button is accessible under an end cap.

This deployment had serious technical problems. We needed to take GPS position throughout the day, from which to determine speed, but we were mindful of the effects this would have on battery life so the sample rate was set at 15-minute intervals. At home and work the device did not get good GPS reception inside. GPS can be supplemented with location derived from WiFi networks, but we had disabled this not wanting to introduce a WiFi configuration step. The consequence of these decisions was that the phone's low-specification GPS receiver infrequently got a good location fix and failed to measure speed reliably.

In this case, we embedded and reconfigured the phone's *display*, *sensors*, *computation* and *networking*.

Figure 4: Connecting Through Housework

Machine 4 - A Message in a Jam

A Message in a Jam (Figure 5) is a machine for a lorry driver who is separated from her family, which allows them to send audio messages to her that are delivered at the point that a traffic jam is encountered. To date it has not yet been deployed.

This Machine was designed for Lisa and Will, who live with their children: Alex (26), Oliver (16), Steve (12), Kevin (11), Billy (9) and Rachel (8). Lisa is a 'tramper', a long distance lorry driver working across the UK. She was away for up to five nights every week, sleeping overnight in her truck cabin. Hold-ups seriously impacted Lisa's day and caused a good deal of stress in meeting tight delivery times. We wondered if we could make a counterpoint to this.

An electronic jam jar at home allowed audio messages to be left for Lisa and the speaker in her cab received these messages - playing them automatically when there was a traffic jam.

At home messages are spoken into the jam jar. Removing the lid starts the recording and the message is sent when the lid is replaced. The glass jar contains custom electronics on a printed circuit board that records audio messages, illuminates the jar to show that a message is contained and connects to WiFi to transfer the recording to the server. In the lorry the speaker contains an Android phone using GPS to determine location and measure speed; in combination with online traffic services it determines if Lisa is currently in a traffic jam and if she is, downloads and replays any new messages from the jam jar.

The speaker contains the Android phone and external amplifier circuit that is powered by an additional LiPo battery; this is charged via a power management module that also charges the phone battery, from a mains adapter. The phone's screen is almost completely obscured by the case, expect for a tiny window that reports status (battery, GPS and data) and allows Lisa to replay recent messages with small touch gestures. Lisa can mute the device using the volume switch on the front that is wired to make a faux touch on the capacitive touchscreen. A power button on the back panel allows her to turn it on and off. This panel can be removed for maintenance and gives access to the phone and its buttons. The phone and electronics are contained within a removable internal frame.

In summary we embedded the phone's *network*, *computation*, *audio* and *multi-touch* technologies.

Machine 5 - Where are You?

Where are You? (Figure 6) is a telescope that allows an eight-year-old boy, Joseph, to find his parents, Emmie and Mark, when they are working away. The telescope lived at home with Joseph, the travelling parent took the mobile 'flag' totem.

By pointing the telescope in different directions and by zooming with the focus wheel, Joseph could explore beyond his village, across whole country and beyond. Inside he saw an illustrated world of towns, cities and landmarks. Wherever Mark and Emmie went, when they planted the flag it would appear in the telescope world. Joseph had a paper map so that he could record these places when he found them. We hoped the telescope would begin conversations either on the telephone whilst the parents were away or when together with the map on their return. The design of this machine is discussed further in [15].

The telescope is constructed from laser-cut acrylic and cardboard, held by elastic bands. It is designed using familiar materials and we asked Joseph to build it for himself with our illustrated instructions. The display is driven by an iPhone that runs a bespoke app using the compass (magnetometer), accelerometer and gyroscope to determine the telescope's position. A click wheel allows the viewing distance to be changed in incremental steps; an Incremental Digital Rotary Encoder is wired to make two faux touches on the capacitive touchscreen. The iPhone is held on an internal frame by elastic bands, which mounts the click wheel and gives access to the power button and charging socket. The telescope obtains the location of the flag from our servers, over WiFi.

The flag totem is also constructed from laser-cut acrylic and cardboard; it contains an Android telephone. When the small acrylic flag is pushed into the hole, it triggers the pressure sensitive screen and our app causes the screen to change color; the current location, determined by GPS, is sent by the mobile data service to our servers. This action, essentially a button press, is deliberately elaborated with the physical flag to make a *moment* of ritual. We find Saffer's *microinteractions* a useful lens [44].

The totem does not track location all the time, only when the action is made to mark that place. The flag will stay visible in the telescope world until it is moved.

The telescope exploits the phone's *display*, *multi-touch*, *sensors*, *computation* and *network*. The totem uses the display, *multi-touch*, *location*, *sensors* and *network*.

Figure 5: A Message in a Jam

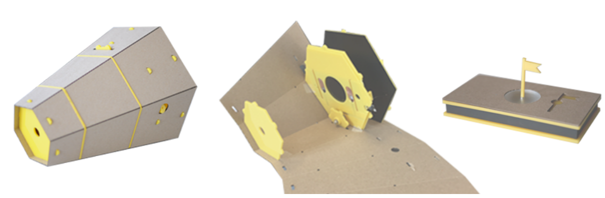

Figure 6: Where Are You?

TECHNIQUES FOR MAKING RESEARCH PRODUCTS

We now identify seven techniques that can be applied by others in making Research Products using the mobile phone as a networked material; illustrated by our Ritual Machines. Each seeks to build the required *finish* and consequential *independence*. In none do we *crack it open*, preferring to build on the integrity (and stability) of the original device.

Making Enclosures

Where we have created a single function device (digital question box, machines 3, 4 & 5) as opposed to an app on a device that continues to function as a *phone* (machines 1 & 2), it has been *embedded* and enclosed. Our intention is to *make it strange* [10], to perturb reading it as *"a mobile phone in a box"*. Our designs manipulate physical affordances to match the new operation of the device. Necessarily, this inherits many of the properties of the enclosed phone; the artifact will always be larger and heavier.

The enclosure does much of our initial work in transforming the device into a Research Product. It frames the initial engagement and is our first opportunity to demonstrate its *finish*. Choice of material and attention to detail demonstrate care and seriousness.

Each of our embedded designs allowed access to the system buttons and the screen for interaction, through their enclosures. For machine 3 the phone could be (and was) simply slid from the case. For the speaker in machine 4, removing the back panel to access the internal frame exposed the three Android system buttons (back, home, overview) - see Figure 7. Our most successful design was the frame for the telescope, giving access to the home button through the fascia and allowing simple removal of the iPhone by removing the elastic bands, allowing complete access – see Figure 8.

Reconfiguring Displays

In all the machines in which the phone is *embedded*, we have reconfigured the display (digital question box, machines 3, 4 & 5) and windowed a portion of it with an unusual circular format. This further defamiliarizes the artifact. For the travelers' totem in machines 3 and 5 we further reduced the graphical capacity of the display to show only simple light patterns. The digital question box and machine 4 predominately shows only white text on a black background. We have deliberately diminished these displays, only the telescope in machine 5 necessarily showed rich color imagery.

As the primary site of interaction for mobile phones reconfiguring the display also reconfigures the interaction, specifically via touch. While this can be managed within the app this does present challenges for configuration and maintenance outside the app where the full-screen and system buttons often need to be accessible; necessitating some means of removing the device from the enclosure.

Extending Interactions - Faux Touch

The Message in Jam (machine 4) speaker has a volume control with an integrated power switch to mute the device; the Where are You? (machine 5) totem device actives when the flag is inserted and the telescope uses has a zoom wheel. In both we extended the multi-touch, making a faux touch on the screen, without additional circuitry or power.

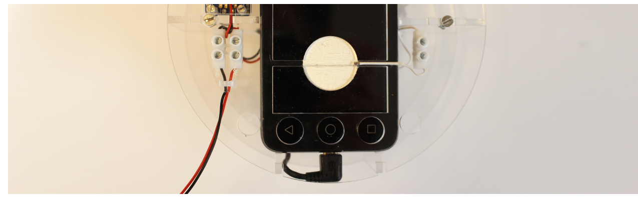

Figure 7: A Message in a Jam – speaker's internal frame access to system buttons and faux touch

The mute switch for machine 4's speaker was our first experimentation with extending a capacitive touch screen, as per Befurt [8]. We used aluminum foil tape, stuck to the internal frame, and held in contact with a region of the screen. This plate is wired through the switch to the device's ground, obtained via the USB charging port – see Figure 7. Ground may also be found through the audio jack or off the case. If the phone has a metal body, this plate needs to be kept out of contact. In this case there is only one input, but there could be multiple. With a UI button component positioned on-screen under the plate, the switch is reliably read and fixed within the frame it is very robust.

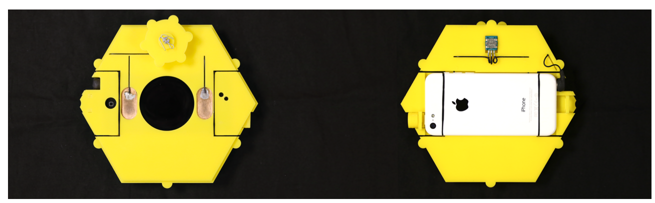

Figure 8: Where are You? – telescope's internal frame

The Where are You? telescope has a wheel that rotates either clockwise to zoom out or anticlockwise to zoom in. We considered using a magnetic effect, as per Bianchi [12], but the telescope already makes use of the magnetometer to obtain a compass bearing. We also considered using the headphone cord volume control buttons, but Apple's SDK does not currently support direct access. Instead we used the capacitive touch technique with an Incremental Digital Rotary Encoder; essentially two switches. After a great deal of experimentation with much smaller foil based plates (including the use of gels and conductive inks between them and the screen) we settled on two relatively large, thumb-sized, copper plates held tight to the screen and read by a *view* supporting multi-touch. The plates are wired through the two switches and to ground, which is obtained from the jack socket. See Figure 8.

Calculating the direction and speed from the rotary encoder relies on precise relative timings of the two switches changing state for each click of the wheel. For a minority of cases direction was decoded in error, typically where the processor had some load. By designing the interaction so that the wheel is rotated by several clicks before the action completed, the direction is reliably resolved with a majority vote.

Surprisingly the Android phone we used for the Where are You? totem device used a resistive sensor. We had assumed it to be capacitive, making prototypes where the flag pushed against a microswitch wired to the screen and conductive ink ran the length of the flag making a circuit between the fingers and the screen. However, it was simply enough that the flag be inserted in the hole, pushed against the screen.

Enabling Networking

There are significant challenges creating the *independence* and transparency of experience we desire with networking, namely: configuration, connection and coverage.

Secure WiFi networks necessitate a configuration step for each location; specifying the SSID and password. Where the device continues to function as the participant's phone (machines 1 & 2), this presents little difficulty; but for *embedded* phones we need to design the configuration carefully - as later described.

Mobile data (GSM) offers a configuration-less location-independent alternative; although the bandwidth can be limited and the data plan usage needs monitoring. Mobile data was used in one way or another by all our machines.

For real-time two-way phatic communication (e.g. machines 1, 2 & 3) a peer-to-peer connection needs to be established. For TCP/IP connections behind a router using Network Address Translation (likely the case with a home network), the IP address of the remote device is insufficient to establish this link. With machines 1, 2 & 3 we used the Yaler (yaler.net) service as a relay, in combination with an intermediary/logging script on our server.

SMS text messaging is useful solution for an incoming connection, in often near real-time. Internet SMS gateways, such as Clockwork (clockworksms.com), allow HTTP requests to initiate an SMS message to be sent. The notification that the robot was paused, for machine 3, was sent in this way. For iOS devices messages can be sent via an HTTP request and the Apple Push Notification Service [4], as we did for the *glass inserted* event in machine 1.

All these wireless network solutions have coverage. All our machines create an alert if the network is unavailable.

Managing Power

As Petrelli et al. [39] suggest power management is a key challenge in repurposing found devices. An attraction of the mobile phone is the integrated battery, charging and power management; including the ability to report the battery level in software. This enables the app to give low power alerts.

In all our embedded designs we have exposed the USB charging point through the machine's case and provided a button mechanically coupled to the soft power button of the embedded device (Figure 9). We could have *cracked it open* and rewired the button, but it was important to keep the integrity of the device for both simplicity and reliability.

Where we necessarily have externally powered circuitry (the Digital Question Box shutter and machine 4's amplifier), we have a single power point. Machine 4's additional battery is charged by the same circuit as the phone, although in this case the charging point its extended to a jack on the back panel.

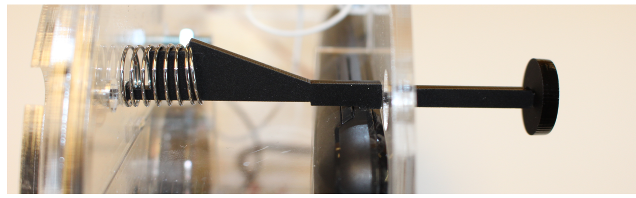

Figure 9: A Message in a Jam – speaker button (side view)

Supporting Configuration

We attempted to reduce the degree of configuration at the point of delivery; if this required the intervention of the family we provided illustrated instructions. For: *embedded* machines 3, 4 & 5 and the Digital Question Box we used mobile data services to give a wide coverage and require no on-site configuration. As noted, this decision had negative consequences for machine 3.

For machine 5, configuration was part of the self-build process, as the family built the iPhone telescope enclosure for themselves. This allowed the WiFi to be configured before the iPhone was attached to the internal frame. Otherwise the faux touch pads obscure vital areas of the screen, preventing configuration. Elastic bands allow easy removal. We continue to seek a good way to configure WiFi from within our apps, or by an externally connected device.

Rewiring Software

Our approach extends the mobile phone with hardware and configures it with software. Given the plethora of technologies inside and the arbitrary connections to be made by networking, the potential of this diversity and complexity is staggering. Being software, its function can be changed at little cost and without physical modification. The software determines the behavior of the machine and further demonstrates *finish* as part of the experience of use.

For the *embedded* machines we need to take over the device. For iOS we used Apple's Guided Access [6] to present our app in a locked kiosk mode, disabling all other access. For Android devices we wrote a lock-screen app that started automatically when the screen becomes locked. By leaving the unlock function unimplemented this runs full screen and reappears whenever the power button is pressed. We necessarily disabled screensavers, key-locks, updates and unnecessary background data.

These techniques can be used on their own, or together, and in a practical way demonstrate how to work with the materiality of the phone at a level of *finish* and *independence* demanded by Research Products.

DISCUSSION

Drawing on our account of the Family Rituals project and the techniques we have developed with this Research through Design process, we now seek to open up a broader discussion for researchers and practitioners using mobile phones as a material in their work – particularly for making tangible Research Products. Essentially we have presented a set of techniques for selecting from an abundance of material properties (technologies and affordances), *purposing* and making them *coherent* and *stable*, and rendering those we disregard invisible. This has been achieved through careful physical augmentation and often complex custom software. There are clear parallels with the approach that Pierce and Paulos' have in rendering their Counterfunctional Things [41]; for example, their Inaccessible Digital Camera.

While our intentions are different, there is a clear point of comparison with Petrelli's encouragement to use found objects and found function for fast prototyping [39]. Our use of the mobile telephone as a material and software, facilitate our Research Products, rather than making our process *fast* per se. Indeed through the case studies and techniques we describe, we show how viewing the mobile phone as a networked material discloses the remarkable affordances of the device. These allow us to produce complex Research Products and experiences with participants that go well beyond the making of prototypes (slow or fast) or hacking found objects.

We have not approached Research Products uncritically. We previously offered some reflections on the properties of *inquiry driven*, *finish*, *independence* and *fit*. Specifically, that we do not see a necessity that the inquiry be future orientated; also that *finish*, *independence* and *fit* may each be manipulated to make the experience strange, to deliberately perturb particular readings – the cardboard construction of the telescope can be seen in this way.

Beyond their status as Research Products, we argue that our Ritual Machines be used for speculation; they are to some degree working artifacts from an alternative present. Our families would not have bought or sought these as products. No such bespoke products would exist were it not for their development for our study. As such there is a degree of fiction, of role-playing, as they negotiate and make meaning with these strange objects within their daily routines. In Wakkary et al.'s [47] terms, interacting with such *counterfactual* artifacts, participants are drawn to *material speculation*. The appropriation of the mobile phone as a networked material might be read in Pierce and Paulos' [41] terms to support the exploration and transformation of counterfunctional devices.

The abundance of technical possibility and the illegibility of behavior from form alone is a powerful tool for material speculation, but raises questions about the way the underlying nature of the technology should be revealed to users; especially over a potentially long deployment. Many of the techniques discussed deal explicitly with this tension – the extent to which the device should be perceived more or less as a phone. How might this support or undermine the speculation? Again this is a point of distinction with technologies developed to a specific brief or a hacked single function device (e.g. a Dictaphone). Participants may be justifiably concerned that the mobile phone within the machine is surreptitiously live-streaming the microphone or logging location, etc.

In Family Rituals, we chose to make the families aware of the nature of the machines. In the printed material we gave them and in our conversations, we were clear that the devices contained mobile phones and made them aware of the information we were (and were not) collecting. In the case of the *Where are You?* telescope, the family configured the iPhone and built it into the device themselves. Hywell and Jesper commented that they enjoyed seeing us engaging in the process of configuring the *Anticipation Machine* as it revealed to them some of the work that had brought it into reality. This all builds trust with the families, on a personal and technical level, contributing to the necessary *independence* of the devices.

Through a long-term deployment there will be inevitable glitches of the hacked device, which expose its phone-ness. These need to be perceived as fleeting and forgettable; moments of 'misfunction', but not long-term malfunction.

CONCLUSION

Our five machines treat the mobile phone as a tangible networked material. In describing seven specific but generalizable techniques, we show how more than a prototype, or hacked device, mobile phones can be reworked to provide the *finish* and *independence* of Research Products. Lastly, we argue that the immense possibilities of a mobile phone as a design material, present opportunities to be used for material speculation.

In this way, we hope to offer the CHI community both practical approaches to exploit the multiple affordances of mobile phones as a networked material, and advance the case for their embedding as tangible and compelling Research Products.

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