Peripheral Tangible Interaction by Analytic Design

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ABSTRACT
Tangible User Interfaces (TUIs) are commonly accepted as those in which the configuration of physical objects embodies digital system state, providing “graspable” digital media that can be manipulated in the focus of users’ attention. In this paper we offer an alternative perspective on the use of tangibility in interaction, in which meaning is created not through precise manipulations of a computationally-interpreted spatial syntax, but through imprecise interactions with independently meaningful, digitally-augmented physical tokens. Users are free to arrange such tokens around the periphery of their workspace, away from their normal centre of attention, ready to selectively and fluidly engage them in loosely related, dispersed episodes of use. We call this concept “peripheral tangible interaction”, and in this paper we describe both our analytic approach to designing a personal desktop TUI supporting such an interaction style, and user responses to its analytically-inspired features during extended deployment in a real office context.

Author Keywords
Tangible Interfaces, Peripheral Interaction, Analytic Design

ACM Classification Keywords
H5.2 Interaction Styles

INTRODUCTION
The notion of peripheral technologies was popularized by Weiser and Brown’s seminal article on *Designing Calm Technologies* [23], highlighting the distinction between designs that encalm and designs that inform. At the very heart of conventional information technology is constant and continual competition for our one focus of attention. “Calm” technology, on the other hand, is about engaging users on the periphery of their attention, through aspects of their environment to which they are attuned but not fully focused. Peripheral technologies are calming because users regain control of information and the process of informing, selecting amongst many peripheral displays and objects for the next momentary focus. Information is pulled by users from their environment as and when appropriate, rather than information being pushed onto them by a range of technologies all competing for their attention.

The field of Tangible User Interface (TUI) research has its roots in Weiser’s vision of ubiquitous computing, aiming to “make computing truly ubiquitous and invisible” [11] by giving physical form to digital information and its control. Weiser’s influence is felt in the distinction between graspable media used to manipulate information at the centre of users’ attention, and ambient media used for passive awareness of information on their periphery. However, whereas Weiser’s vision of calm technology “engages both the center and the periphery of our attention, and in fact moves back and forth between the two” [23], the historic distinction between focal graspable media and peripheral ambient media reifies the notions of centre and periphery as fixed categories of the world, rather than treating them as dynamic states of the mind.

Our goal was therefore to design a TUI based on tangible objects that could drift between the focus and periphery of a user’s attention according to the momentary demands of their activity. Rather than simply creating a low-attention interface, however, we wanted to exploit the affordances of physicality to facilitate the “engaging user experiences” of Rogers [19], in which “people rather than computers [...] take the initiative to be constructive, creative and, ultimately, in control of their interactions with the world – in novel and extensive ways”. This combination of calm peripheral interactions and engaging tangible interactions is the essence of what we call *peripheral tangible interaction*.

In this paper, we describe the way in which we integrated multiple perspectives on interaction as an *analytic design process*; our application of this process to create a TUI supporting tangible peripheral interaction in the office context; and an evaluation of its analytically-inspired design features based on use in a real office setting.

DESIGN PREVIEW
The application domain of our TUI is personal and group task management, where individual tokens represent unfinished tasks and shared documents. Members of a team can use the system to track and update task progress and dependencies between tasks. We aim to support fast and fine-grained management of group activity, at a level that

improves by some orders of magnitude over the current generation of project management tools.

The system we describe uses a number of familiar TUI design approaches. It uses an interactive surface on which tokens can be placed, with token position and identity recognised by a camera mounted above the surface. When on the surface, tokens are visually augmented by conventional display "halos" displaying their attributes. This technique is common to many applications of the interactive surface form, such as the reacTable [12].

At the same time, our TUI is unusual in a number of ways. We use a tablet PC as an interactive surface, but not as a pen computing or touch device. We use a commodity webcam to track tokens placed on this surface, but we do not interpret their positions or arrangement in space. Our system uses both hands, but not at the same location. Our tokens are designed for robust recognition by the system, but we also emphasise the tangible function of these tokens when they are not on the interactive surface. The following section describes the way in which our design (Figure 1) was influenced by multiple analytic perspectives drawn together from across the TUI literature.

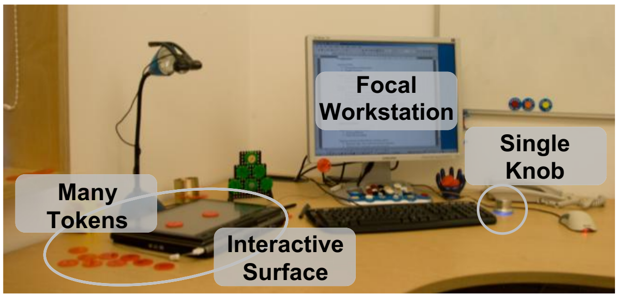

Figure 1. Structural design of TUI

ANALYTIC DESIGN PROCESS

Whilst many presentations of TUI systems cite insight as the origin of design concepts, or intuition as the method of selection between competing designs, such descriptions fail to reference the models, theories and frameworks that are tacitly and implicitly drawn on by experienced designers.

In this paper, we describe the *analytic design process* that we followed in creating a TUI for peripheral tangible interaction. Design is *analytic* when it is broken down into its elemental components, with each of these components being analyzed individually. Rather than marginalizing the role of creativity in design, we believe that such an approach can actively assist designers in their discovery of creative design solutions. We present the resulting design as the product of a linear *process*, even though in practice our approach was highly non-linear. This is because we also believe that if a design cannot be rationalized as a logical progression from problem to solution, then there is a fundamental problem with that design. This approach is called "faking a rational design process" [16], and originated in software engineering from the suggestion that designers need guidance, and will come closer to achieving a rational design if they adopt a reflective process that encourages them to think in such a way.

As such, our analytic design process can be viewed as a rational, progressive refinement from a design context to a meaningful design, proceeding across four stages:

1. **Context analysis** identifies the activities in a context that could benefit from TUI support – it refines a *design context* into a *design opportunity*.
2. **Activity analysis** describes the properties of a TUI that would appropriately support these activities – it refines a *design opportunity* into a *design space*.
3. **Mapping analysis** generates the physical-digital mappings of a TUI structure with these properties – it refines a *design space* into a *structural design*.
4. **Meaning analysis** provides these mappings with meaning that users can understand and adapt – it refines a *structural design* into a *meaningful design*.

We will now describe each stage in detail, introducing the theoretical concepts that underlie each analysis type, our translation of these concepts into probing design questions, and the use of these questions to inform the design of a TUI that supports our concept of peripheral tangible interaction.

Context Analysis

The context in which we decided to investigate opportunities for peripheral tangible interaction was the ordinary office, in which the work of individuals is typically inter-related but predominantly performed alone at their desks. We adopted an approach to *context analysis* based on a high-level decomposition of context into four distinct aspects that impact upon the situated accomplishment of work activities:

1. *Structural context*. How are activities distributed across people, artefacts, and space?
2. *Procedural context*. How are activities initiated, coordinated, and completed over time?
3. *Cognitive context*. How do the cognitive demands of activities compare to the means of cognitive support?
4. *Social context*. How do the social demands of activities compare to the means of social interaction?

We used these questions in two distinct ways. Our first was as macro-level thematic elements of semi-structured interviews with technical staff, managers and executives at a multinational company. These interviews uncovered a number of problems with existing work processes and practices. In particular, the multicast, asynchronous, and archivable characteristics of email meant that it had become the standard for workplace communications. This resulted in a state of overload, in which information became hidden or lost due to the homogeneous appearance of emails, the invisibility of older messages, and the inconsistency of personal message organization. Another consequence was that there was less reason for people to meet face-to-face. Combined with the standard practice of weekly project meetings, this had resulted in a general lack of awareness about the work status of other team members. These were formally updated once a week during the project meeting, but rarely at other times. To compound matters further, the status updates that did occur were collected by email.

Other problems related to the guesswork involved in timesheet completion; the difficulty of sharing information recorded on physical media such as note books, whiteboards, and Post-Its™; and the inappropriateness of planning work in calendars. In all cases, the problems appeared to stem from the interactional and attentional costs of creating and updating digital information structures *about* work, in parallel with actually *doing* it. Such *auxiliary work activities*, of which email management, timesheet completion, information sharing, and work planning are all instances, can often become marginalized or forgotten due to the pressures of multitasking. Encouraging conversation and aiding auxiliary work thus became our candidate for tangible peripheral interaction.

The second use of our context analysis questions was as the basis of *micro-level* coding categories for a video study of desk work. Having returned to the company and recorded half a day's footage of an engineer working at their desk, we selected a 30-minute period of typical workstation-intensive activity for second-by-second analysis.

For about half the time, both hands were engaged in typing or coordinated use of keyboard and mouse. For a quarter of the time, however, the subject's hands were not engaged in workstation-based activities; rather, he was attending to events happening around him. This sizeable proportion of non-workstation activity during what was a workstation-intensive task (software debugging) presented a design opportunity, in terms of both exploiting natural breaks in activity to perform peripheral updates, and providing users with a way of recovering their work context after interruptions. In addition, during the remaining quarter of the time there was a notable difference in observed hand usage. When only one hand was actively operating the keyboard or mouse, the right (dominant) hand was employed for twice the duration of the left hand (164s vs. 81s). However, this asymmetry was reversed when idling (non-workstation) behaviour was considered: the left hand was observed tapping, fiddling, scratching, screen grasping, gesturing, and resting for almost four times the duration of the right hand (283s vs. 71s). When not using the keyboard and mouse, the engineer also regularly used his right hand to touch objects to the right of his keyboard, without diverting his visual attention from his monitor screen. His desk phone, mobile phone, mug of coffee, and bag of confectionery were all acquired in this eyes-free manner. In contrast, he did not touch the various piles of documents and books on the left hand side of his workspace, although he did refer to and update the whiteboard located above them throughout the recorded period.

Activity Analysis

The application of context analysis resulted in a better understanding of how appropriate different forms of interface and interaction might be for supporting the activities of that domain. The goal *of activity analysis* was then to describe the abstract requirements of contextual activities in terms of the interfaces that might support them.

An existing analytic framework for TUI design is the *Tangible Correlates of the Cognitive Dimensions* [4], which distinguishes between multiple dimensions of usability. We converted each into a probing design question about the usability requirements of tangibles in context:

1. *Bulkiness*. To what extent do activities require spatial representations that extend in three dimensions?
2. *Hidden augmentation*. To what extent do activities require digital augmentation that is physically obvious?
3. *Juxtamodality*. To what extent do activities require parallel but decoupled observation and manipulation?
4. *Permanence*. To what extent do activities require the preservation of physical structures for later inspection?
5. *Purposeful affordances*. To what extent do activities require afforded actions be interpreted by the system?
6. *Rigidity.* To what extent do activities require low resistance to changes in physical object configurations?
7. *Rootedness*. To what extent do activities require low resistance to changes in physical object locations?
8. *Shakiness*. To what extent do activities require protection against hard to reverse physical changes?
9. *Structural correspondence*. To what extent do activities require similar physical and digital structures?
10. *Unwieldy operations*. To what extent do activities require low levels of physical manipulation difficulty?

Based on the preceding context analysis, we identified five key requirements for supporting auxiliary work. Tangible representations should exhibit *low bulkiness* to minimise consumption of valuable desktop space, *high permanence* to ensure information availability, *low shakiness* to guard against accidental changes, *low rootedness* to allow free movement around and exchange, and *low rigidity* to support rapid, direct interactions in parallel with workstation tasks.

Mapping Analysis

Having generated usability requirements for the office context, we used *mapping analysis* to describe the physical-digital relationships of potential design solutions and to compare their usability properties to these requirements. We identified three aspects of such mappings, based on TUI *styles of mapping* [21], post-WIMP *instrumental interaction* [2], and graspable UI *multiplexing* [7].

1. *Spatial mapping*. How are the physical configurations of objects computationally interpreted?

2. *Action mapping*. How do physical actions lead to digital effects, in terms of indirection and compatibility?
3. *Attribute mapping*. How do physical object properties relate to digital information attributes, in terms of integration and multiplexing?

Our application of mapping analysis resulted in an interface particularly suitable for the activities to be supported, yet different from most existing TUIs in two significant ways.

Spatial Mapping: Freedom from Spatial Syntax

Our notion of spatial mapping is based on the typical *styles of mapping* for TUIs – spatial, relational, and constructive – all of which impose a *spatial syntax* on the placement of physical objects, defining how any arrangement will be interpreted by the system. The aim of such spatial syntax is "to take advantage of natural physical affordances to achieve a heightened legibility and seamlessness of interaction between people and information" [11].

However, our comparison of the usability properties of spatial syntax with the requirements of the office context highlighted a number of incompatibilities. In particular, the use of spatial representations would result in *high bulkiness*, since they require a larger desktop footprint to accommodate spatial arrangements; *high shakiness*, since they can change state after accidental but common incidents such as knocking; and *low permanence*, since meaning can persist only until constituent parts are needed elsewhere.

These properties are all in conflict with the requirements of the office context that we identified in the previous section. This suggests that while spatial syntax is appropriate for problem domains that are inherently spatial – such as the building layout in Urp [22] or the landscaping TUI of Illuminating Clay [18] – the use of spatial mappings to represent abstract relationships is subject to the disadvantages of TUIs without being able to exploit familiarity with physical objects and their known uses. In addition, within the six fundamental forms of spatial relation [5], we identified a trade-off between *rigidity* and *rootedness*. Whereas relationships based on physical bonding (connection, stacking or containment) are easy to move as a unit but more difficult to reconfigure, those relationships based on perceptual arrangement (lines, clusters, separated regions) are easy to reconfigure but more difficult to relocate. Since the office environment requires compact, persistent, and robust representations that are both easily updatable and easily portable, we decided to investigate non-spatial solutions in which the individual tangible was the largest unit of representation. Each would represent something of shared importance, indicated by our context analysis to be *tasks*, *documents*, and *people*.

Spatial Mapping: Decoupled Representation and Control

The challenge was then to create a non-spatial syntax based on independently-meaningful tangibles. Inspiration came from our contextual video study, in which we had observed the potential for two-handed interaction customized to the laterally-specialized spaces at the sides of the subject's workstation. Such *bimanual interaction* is typically asymmetric – for right-handed people[1], "right-hand motion is built relative to left-hand motion, corresponds to a temporal-spatial scale that is comparatively micrometric, and intervenes later in the course of bimanual action" [8].

These characteristics account for our everyday actions in the real world, in which bimanual cooperation entails both hands operating on the same physical objects, in the same physical space. However, in terms of interacting with computers and other electronic devices, bimanual cooperation is not constrained by the limits of the natural physical world. Interaction with virtual objects tends to be through parallel, rather than serial, coordination of the hands. In typing, this parallel cooperation is symmetric, whereas in the coordinated use of the keyboard and mouse the cooperation is asymmetric. In the latter example, this parallel division of labour exhibits the same characteristics as the serial division of labour described by Guiard [8].

This observation suggests that our interaction with virtual worlds is influenced by our asymmetric bimanual conditioning in the physical world, which in turn is influenced by the neurophysiological differences that lead to lateral manual preference. It is therefore possible to imagine a *conceptual link* between the virtual output of the left hand and the virtual input of the right hand, even if the hands operate in disjoint physical spaces. This phenomenon has been confirmed experimentally by Balakrishnan and Hinckley [1], under the condition that there is adequate visual feedback for bimanual coordination. The implication for TUI design is that the two hands could interact with different aspects of the same digital information. In particular, one hand could be dedicated to selecting between multiple *physical representations* of digital objects, with the other dedicated to *physical control*.

According to the Guiard principles, assuming tangible tokens represent digital objects with multiple attributes:

1. The left hand should lead, being used for coarse-grained selection between multiple tokens and their attributes, setting a reference frame for visual attention.
2. The right hand should follow, acting within this frame of reference, performing fine-grained manipulations of the selected attribute with a single control device.

By facilitating cooperation between the time-multiplexed operation of many tokens under the left hand (analogous to keys on a keyboard) and a control knob under the right (analogous to the mouse), the resulting *decoupled* TUI structure naturally complements the traditional workstation of monitor, mouse and keyboard.

[1] Assuming the person is right-handed – for left-handers, reverse left and right throughout the rest of this paper.

These insights led to the basic structural design of our TUI, as shown in Figure 1. The primary component of the interface is an interactive surface placed to the left of the keyboard (for a right handed user). When a physical token is placed on this surface, its position and identity are determined, and the information attributes associated with that token are displayed underneath and around it as a "halo" on the interactive display surface. For example, a task token might show its name, time spent on the task so far, the estimated time remaining, the due date, and so on.

To interact with an attribute of any such token, the left hand leads by nudging the token in the direction of the desired attribute as it is rendered in the token's digital halo. This initial, coarse action assigns control of that attribute to a rotary knob. The right hand then follows, turning the knob in a fine-grained motion to adjust the selected attribute.

The peripheral interaction style supported is thus:

1. *Glance* at the surface from time to time
2. *Nudge* tokens to select attributes to change
3. *Turn* knob to change the selected attribute

This deliberate recruitment of both hands also ensures that actions are intentional. This helps to reduce *shakiness*, since the extent of change possible by accidentally knocking tokens is a change in the current selection, rather than any change in value. This "bimanual safeguard" allows users to make rapid, intentional changes (*low rigidity*) whilst sustaining tokens being moved around on the surface, taken off and even passed between individuals for use on other surfaces (*low rootedness*). The combination of complementing the existing workstation and supporting rapid interactions means that fluid switching is possible between the workstation used for primary work tasks, and the TUI for auxiliary activities. The design therefore meets all of the interaction requirements of the usage context.

Action and Attribute Mappings

As part of a TUI's action mapping, *indirection* and *compatibility* respectively denote the spatiotemporal offsets and similarity between physical actions and digital effects [2]. Our interface structure exhibits low *representational indirection* between the locations of physical tokens and their digital halos, but high *control indirection* between the locations of the single knob and the many tokens. There is also high *representational compatibility* between token and halo movement, and high *control compatibility* between physical knob actions and visual attribute changes.

The attribute mappings of the interface archetype are similarly of two kinds. As part of a TUI's attribute mapping, *integration* denotes the match between the physical degrees of freedom of a device and it's digital dimensions of control [2], while *multiplexing* denotes the permanence and multiplicity of the associations between the physical and the digital [7].

Our TUI structure has high *control integration* since the single-degree-of-freedom (1-DoF) of the control knob maps onto one-dimensional (1D) attributes. This is appropriate, since the nature of information attributes that can be rapidly perceived and manipulated will typically be 1D (quantities, indices, lists, etc.). Of the six prototypical 1-DoF device structures – knob, joint, length-slider, position-slider, length-screw and position-screw [4] – only the knob has the required characteristic of "statelessness" that allows it to be multiplexed between many information attributes. This characteristic also allows the knob to be acquired and operated in an eyes-free manner, with its position between the keyboard and the mouse minimizing the average "homing" distance required, and exploiting the complementary muscle memory and spatial memory arising from many interactions with a device in a fixed location.

Conversely, our TUI exhibits low *representational integration* since the many possible nudge directions map onto a small, quantized number of attribute selections. This is a necessary part of the bimanual control schema, enabling coarse-grained attribute selection. Regarding the number of attributes such halos should contain, there is a trade-off between information content and precision of selection. Given that the TUI is designed to support peripheral actions, the number of attributes should be limited to what can be perceived "at a glance" and selected between using a small set of coarse-grained "nudge" gestures. Restricting these to the four surface-aligned directions provides a reasonable balance between the information content and the required levels of perceptual acuity and motor precision.

Meaning Analysis

Whereas mapping analysis examines the deep structure of an interface design, *meaning analysis* is about how users will perceive and interpret its surface "look and feel".

The interactive surface was provided by a Toshiba Tecra M7-102 tablet PC, with a Logitech Quickcam Fusion webcam pointing at it from above for token recognition. A Griffin Powermate was used as a knob-based control that also incorporated short and long "click" button characteristics. Our tokens are circular discs, laser-cut from sheet Perspex, about the size of a poker chip (35mm diameter × 4mm thick). Each has a unique pattern of holes cut around its edge (Figure 2), so that vision algorithms based on fast radial symmetry detection [14] can be used to identify and track tokens placed on the surface.

Task tokens are red, with edge textures unique to their owner (Figure 2, left). When placed on the interactive surface, they display attributes aiming to support the task coordination needs of potential users as discovered in our contextual interviews. Likely completion date (a) is shown by an arc extending from the top of each task token to the corresponding date in a calendar along the top edge of the display surface (b). *Hours work remaining* (c) is represented on the right of the halo by a series of five overlapping, semi-circular scales, showing durations up to

1, 4, 10, 40, and 100 hours respectively. Each scale is broken down into twelve increments, allowing time estimates to be specified at a granularity commensurate with their probable accuracy. When the user adjusts the time estimate, a second arc (d) extends backwards in time from the completion date, taking into account the number of overlapping tasks to show the last date on which the task could be resumed and completed in a timely manner. Presentation of such *latest restart dates* provides an "at a glance" visualization of workload based on task urgency.

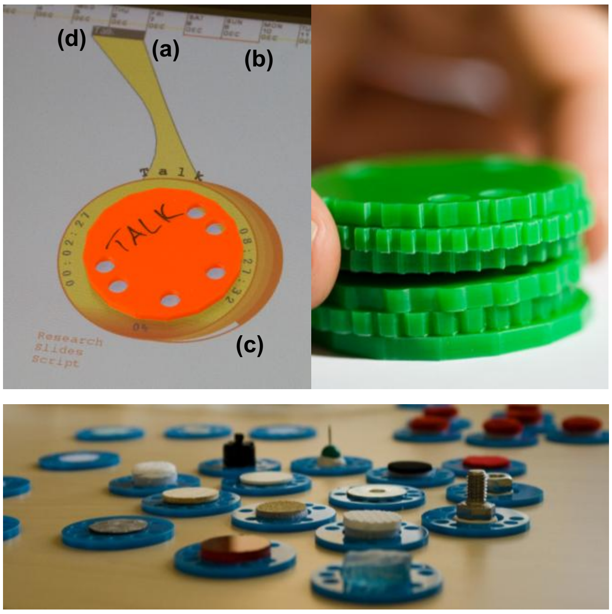

Figure 2. Surface design of tokens

Contact tokens are green, also with edge textures corresponding to the user they represent (Figure 2, right). A user can set a status message using her own contact token and visualize the status and work schedule of others by placing their contact tokens on her interactive surface. Document tokens are blue, with circular recesses in their upper face. These support the attachment of small objects or distinctive materials that we provided for the purpose of customization (Figure 2, bottom). Document tokens act as physical links to shared web documents implemented using the open-source SynchroEdit software [20].

These design decisions were aided by meaning analysis – considering the *legibility* of the design in terms of the relationship between what is perceived by the user and what was meant by the designer. Meaning analysis helps the designer tell a plausible story about how users will interpret the perceptual and conceptual rendering of the interface as a meaningful system in four distinct ways:

1. *Visual meaning*. How does the visual appearance of each interface object suggest action possibilities?
2. *Haptic meaning*. How does the haptic experience of using each object guide action performance?
3. *Functional meaning*. How does the physical form of each object signify its conceptual function?
4. *Relational meaning*. How does the spatial configuration of objects signify conceptual relations?

Our notions of visual meaning and haptic meaning derive from Norman's concepts of *affordance* and *feedback* respectively [15]. One of the most important visual cues in our system is the token size. We decided to use poker-chip sized tokens to provide a balance between users being able to identify tokens from their surface markings, and being able to manage many such tokens spread throughout their desktop environment. Such tokens can also be transported easily in the hand or pocket for exchange or discussion with other people. Our approach to token identification through circular patterns of holes also makes the means of digital augmentation explicit, as well as leaving the centre of the token surface available for surface annotation using dry-wipe markers. Finally, the textured edges of task tokens provide distinctive visual and tactile qualities for rapid discernment of delegated tasks relative to one's own. The size of the interactive surface relative to the size of tokens provides another important affordance. Given that the two dimensions of the interactive surface are not meaningful in themselves – they are simply used to provide an area in which the digital attributes of tokens can be visualized and selected – the size of the interactive surface can be chosen according to the trade-off between loss of desk space and gain in visualization space. We chose tablet PCs because they could accommodate a handful of poker chip-sized tokens without consuming excessive desk space (Figure 3).

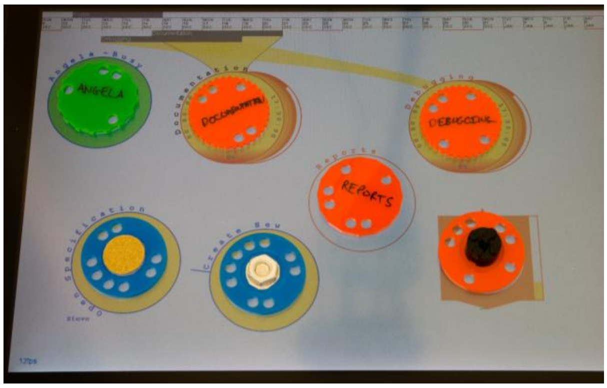

Figure 3. Token layout on tablet PC interactive surface

In terms of haptic feedback, our choice of Perspex as the token material provided tokens with sufficient weight that purposeful nudges are required in order to displace them on the surface (i.e. to select attributes), but of insufficient weight for the tokens to damage the display surface if casually thrown onto it. Similar consideration regarding the control knob resulted in the selection of a Griffin Powermate USB controller, which combines the physical characteristics of low friction and low rotational inertia desirable for rapid yet accurate manipulations.

The functional meaning of interface elements can be understood from the perspective of *semiotics*, or the science of signs [17]. In particular, individual interface elements can signify their function *iconically*, through similarity to it; or *symbolically*, through arbitrary convention (a distinction used by Dourish in his classification of TUIs [3]). In our interface, physical tokens symbolically stand for digital information. This link is arbitrary and needs to be learned, but is both simple and memorable. The link between any particular token and its "content" is not purely symbolic, however: it is denoted through surface annotations of the token that further describe its digital information content. This makes identification easier once the token is in hand, but not at a glance. For this purpose, the attachment of physical materials or objects to tokens can aid the recall of token identity as well as its recognition in the environment.

Relations within and between tokens and the desktop environment, although not interpreted by the TUI, can nevertheless provide a physical means through which users can furnish their environment with meaning they can subsequently reason about. The way in which humans perform such abstract reasoning is the focus of Lakoff's *spatialization of form hypothesis* [13] – that we structure our bodily experiences preconceptually using *image schemas*, mapping them metaphorically to the conceptual structures we use in abstract reasoning. A corollary for TUIs is that we can use the same image schemas to project meaning back onto the world, by virtue of the structural isomorphism underlying metaphor. The potential use of image schemas in TUI design has also been advocated by Hurtienne and Israel [10], in which they derive "metaphorical extensions" of image schemas that are directly applicable to tangible structures. Their essential point is that designers should be able to explain their constructions in terms of image schemas and their metaphoric projection onto TUI syntax. Our notion of relational meaning is based on a broader consideration of meaning in TUIs, not confined to their formal syntax. In the words of Dourish, "it is important not to imagine that the application's boundaries contain everything that matters" [3]. Our tokens can be stacked, laid out in lines or clusters, placed in indexical relation to already meaningful desktop objects, or organized using physical props – acquired or constructed by the user specifically for the purpose of token management. This shift from system to user-centred meaning has been referred to as "acknowledging offline interaction" in the practice-turn of TUI research [6].

EVALUATION

Our TUI was used by three members (P1, P2, P3) of a local technology company for five weeks. During that time, our software recorded over 4500 knob press/turn actions. While our primary goal in this paper is to present the systematic way in which we designed a TUI for peripheral tangible interaction, we now present user feedback regarding those aspects of the TUI inspired by our approach. We use Hornecker and Buur's four themes of tangible interaction [9] to structure this discussion of how our interface was experienced as both "calm" and "engaging".

"Spatial Interaction": Peripheral Interactive Surface

The benefits of the interface exceeded all users' opportunity costs of desk space, with P1 happy to give up "another volume of A4 paper". P2 agreed that "allocating that amount of space wouldn't be a problem", but noted that the sides of the tablet PC impeded the process of sliding tokens on and off the surface (easily addressed in future with a screen embedded in the desk surface). P3 remarked that "You have to choose what's most important at that point in time, but you can still see enough tasks so that you don't have to always keep moving them on and off the surface", supported by her view that "If you had a massive surface and could just throw everything on there, I don't think you'd be as focused". Both P1 and P2 thought that eight tokens on the surface at any one time would border on being "cluttered", whilst P3 thought that four or five was optimal in order to avoid "confusion". Both judgements are consistent with Miller's 'magic number 7 +/- 2'. P1 described her approach as looking at the surface "often enough just to refresh my mind about the tokens that are on there … certainly looking at it about every twenty minutes, probably twiddling with it about every half hour or so".

"Tangible Manipulation": Bimanual Control Style

The bimanual control schema was also well received by all users. P2 said that "The nudge to select, the short click to activate, and the long click to edit is actually pretty good … it just makes sense, how it works"; for P1, "It all seems really smooth"; while for P3, "It's very simple to just move something and click – that's quite easy to remember!". P3 described her interactions as "more a bit of a glance and a quick play around to make sure everything is on track … every hour or so". Switching between tasks posed no problem for P1, "I'm putting a token on if I'm doing something different and using my Powermate thing to switch quickly", nor did eyes-free acquisition of the control knob: "I would just sort of glance over at the tablet to make sure that I was nudging the right token, and the Powermate is just there so I don't really need to look". This was backed up by P2: "It's quite easy to find because it's a big object".

"Expressive Representation": Material Customization

In terms of token annotation, P3 said that "I think the material was a good choice … you can write on it and wipe off easily, and you can also stick things onto it". P2 noted "how easy" it was to take a token and write on it. Token adornment also had advantages in terms of interaction. P1 described the "sphere" attached to her "Meta" token as "a kind of handle with which I can pick the token up and move it around; it's really quite satisfying!". Similarly, P2 attached a magnetic rod to his calendar token that allowed him to "pick it up easily and place it accurately on a 'busy' surface". Token augmentation also provided an "aid to identification" according to P2, who also liked to give "badges" to his task tokens to identify their "group". Finally, P3 thought that tokens were "a way of things not getting lost", because "Something physical is always easier to see and to find than something that is just in your head".

"Embodied Facilitation": Social Exchange

Tokens can also be used away from the interface in group situations such as meetings. P1 noted that for a future set of tasks she and P2 had coming up, "it would be useful to lay them all out and divide them between us – certainly better than just divvying up a list". Such social exchanges *around tokens* are complemented by the social exchange *of tokens*:

> *Tokens can give you an excuse to go over to people's desks and speak to them, and it would help you, when you're doing a task that someone has given you, that you've had a few minutes when they've handed the token over to you to confer and get confirmation of what you're both working on. Tokens actually encourage that person to walk over and talk to you.* (P3)

CONCLUSION

In this paper we have described how our adoption of an *analytic design process* helped us to systematically explore the TUI design space, and explain why TUIs based on *spatial syntax* are inappropriate for supporting *auxiliary activities* in the context of desk-based office work. Our asymmetric interface structure, based on a *decoupling* of representation and control to support *bimanual interaction*, means that it doesn't conform to the conventional Model-Control-Representation (Physical + Digital) TUI archetype [21]. However, our evaluation of the interface in a real office context indicates the value of such decoupling, the utility of our analytic approach, and the potential of *peripheral tangible interaction* to deliver both *calm* and *engaging* qualities in future tangible user interface design.

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