WASEDA UNIVERSITY

Augmented Reality Interaction Paradigms for Daily Productive Tasks

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Abstract

Despite the major advances in computing, such as wearables and mobile devices, the majority of people and professional entities remain relying on desktops and laptops for productivity related tasks. The mentioned trend led to destructive ramifications towards us, mainly in terms of withdrawal from the real world, health deterioration and interaction inefficiency. In response to the mentioned implications, we propose an approach that bears characteristics that is human-centric. Our approach essentially emphasizes concepts of computer invisibility, natural interaction, mobility and task efficiency. To further investigate our approach, we have applied our core characteristics on a daily usability problem; which is parallel web browsing. Parallel browsing is the behaviour of concurrently visiting multiple web pages. Our approach attempts to support parallel browsing with an Augmented Reality web browsing environment that mainly relies on Tangible Interaction. To verify our approach, we developed a prototype and carried out a short user-study. In a web-content comparison scenario, 70% of participants achieved a 21.4% decrease in the time required to complete a comparison task with our prototype. Further analysis additionally indicated statistically significant difference in favour of performance on our prototype. Moreover, we have found further advantages that were traced back to our approach's core characteristics, resembled in flexibility of movement, reduced memory load and learning time. The results collectively steered the vision of interaction through our approach. Therefore, we investigated various themes surrounding user-defined multimodal cross device interaction, encompassing sub concepts of abstraction and cohesiveness of the whole interaction experience. Finally, we concluded that our approach had provided good evidence of its' potential to contribute to shaping the future of human computer interaction.

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1 Introduction

As conventional computing, represented in Laptops and Desktops, is being unprecedentedly surpassed in production by various mobile and wearable devices, innovative means of human computer interaction (HCI) emerge, enabling further and better utilization of digital devices [**13**]. In parallel to the previously mentioned development, it is a fact that the majority of people remain relying specifically on Laptops and Desktops for productivity applications, rather than other mobile devices, especially in professional work environments.

Even with the increasing adoption of mobile computer devices in professional work environments [**13**], as Mark Weiser[**3**] concluded, the general forms of computer devices suffer from a crucial core issue; isolation from reality. To elaborate, all mentioned computer devices demand almost complete attention upon usage [**3**]. In addition, modern devices enforce, upon the user, specific and unnatural interactivity mechanisms for operation and utilization. Such procedures require a learning process that would potentially consume valuable time. Furthermore, mentioned flaws worsen when productivity is essential; since we consider that productivity requires constant level of concentration, the user will be trapped in the location where the computer device is and to the screen of the computer device to accomplish tasks.

The combination of all the mentioned issues, for the majority of productivity tasks, have led to a work-culture that equates productivity to sitting in a room in-front of a monitor with a keyboard and mouse for an extended number hours. Given that the working time per day, on average, is approximately 7 hours [**14**][**15**], such behaviour could have devastating chronic impact on health, resulting in fatigue, diabetes, heart disease, musculoskeletal pain, among others, which could result in death[**16**].

As a result, we believe it is far more important than ever to redefine the relationship between humans and computers. We believe computers should be remodelled from a human-centric perspective; directly emphasising human physiological and psychological characteristics, abilities and needs. In this project, we focused on computing from the perspective of current and everyday life. Later, we proposed a prototype that enhanced productivity of a daily task using human-centric interaction techniques. We additionally presented our results followed by an analysis and conclusion. Finally, we presented the vision of our approach and its potential to positively contribute to human computer interaction as a whole.

1.1 Design Ramifications

The main problem with current computer usage habits can be summarized in the following:

1. Isolation from the Real World

The majority of digital devices demand almost complete attention upon usage [**3**]. This phenomenon is very evident when using mobile devices while commuting, as people constantly bump into objects or walk towards an unintended direction; since users are almost fully unware of their surroundings. This presents a serious issue as it segregates users' interaction into real-world interactions and digital world interactions.

2. Limited Mobility and Portability

Regardless of modern advances in portability and mobility aspects, digital devices are yet to fully support essential mobility needs. First, most devices constantly need to be recharged at least once on daily basis. Most devices are additionally incapable of functioning over extended periods of time. Many users carry smart phones, tablets, smart watches and a laptop, so users usually carry 2 or more devices when commuting. While research has shown that each device essentially serves a definite or numerous purposes [**34**], carrying these devices require a cost in terms of the device's capabilities, weight and occupied space. Since current generation devices lack in one or more of the mentioned aspects, current form of digital devices consequently hinder our ability to be commute lightly.

3. Inefficient Interaction

The overreliance on keyboards and a pointing device led to the wide adoption of WIMP (**W**indows, **I**cons, **M**enus and **P**ointers). For example, in a text editor, we highlight and enter text using a pointing device and a keyboard, respectively. Additionally, we adopt the same behaviour for browsing the web, editing videos, playing games, checking stocks and all sorts of productive and consumptive daily task. While a

Keyboard and Pointing Devices are very suitable for some tasks, we believe that it has become inevitable that most applications are precisely designed to be compliant with these input combinations (**Figure 1**). Moreover, it is illogical to think that a single set of I/O devices could yield superior usage traits in all forms of tasks. Modern devices enforce, upon the user, specific and unnatural interactivity mechanisms for operation and utilization. Such procedures require a learning process that would potentially consume valuable time.

Furthermore, research has constantly indicated the ramifications of designing tasks around unsuitable I/O approaches. Jacob et al [**30**] specifically indicated that the structural connection between input devices and tasks is of utmost impact on performance, proving this relationship to be of more significance than exclusively studying input devices or tasks. Their studies additionally concluded that, to select a suitable input device for a task, an intensive perceptual-structure analysis of the task at hand is a critical requirement towards successful selection. Accordingly and in contrary to Jacob et al's findings, the modern user experience is almost the opposite; user experience on a device is defined by whichever available input and output devices (**Figure 2**).

Figure 1: This figure illustrates how available input and output devices determine how we accomplish most tasks, which contradicts established evidence from previous research [**30**].

1.2 Our Approach's Characteristics

We intend to proceed without approach by extending 4 main principles:

1- **Invisible:** By weaving technology with the surrounding environment, whether natural or urban, we attempt to reach human-sensory calmness and natural harmony.

2- **Natural Interaction:** To be able to interact with computers in similar fashion to the real world. To have technologies that corresponds to our natural abilities.

3- **Mobile:** To support human nature of constant motion and movement.

4- **Task Oriented Interaction:** We attempt to adapt interaction that best reflects task-accomplishment attributes.

Our approach's main concept is to find traceability among human natural traits and computing. Thus, we attempt to develop a user experience that best reflects human needs and task requirements.

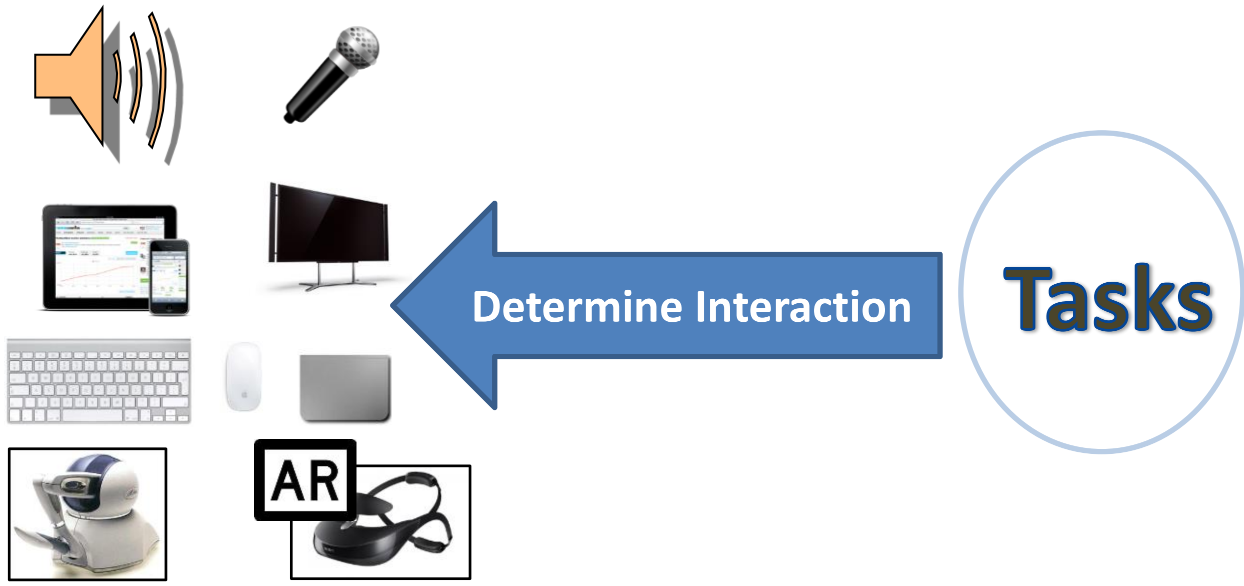

Figure 2: This figure shows how interaction with a task should be modelled. Task attributes must be reflected on the interaction to select the most appropriate I/O mediums [**30**].

2 Parallel Web Browsing in Tangible Augmented Reality Environments

2.1 Introduction

Parallel browsing is the behaviour of concurrently visiting multiple web pages [**17**]. Parallel browsing is becoming a crucial part of the modern web browsing experience in all types of devices. For instance, in a search engine's results page, users often open a new tab for each of the search results. Users may also compare two or more search results in side-by-side browser windows [**18**]. Common web browsers support parallel browsing through multiple browser windows and tabs.

In modern web browsers, the integration of multiple windows and tabs reflects essential parallel browsing user requirements. For example, users often need to compare contents from multiple web pages [**3**] or search for multiple topics in a single web session [**19**,**20**]. Nevertheless, user studies have specified a number of significant interaction-oriented flaws in multiple windows and tabs. For instance, in certain parallel browsing scenarios, tab switching consumes a lot of time (More details in Problem Analysis).

Furthermore, users' tendency to adopt parallel browsing behaviour has been analysed in numerous user studies [**21**, **22**]. Mentioned publications concluded that in order to affectively support parallel browsing, we need to sufficiently study parallel browsing users' behaviour, techniques and technologies.

Therefore, due to the shortcomings of multiple windows and tabs, our project aims to explore new methods and techniques to efficiently support parallel browsing. Our approach is based on integration of Augmented Reality (AR) and Tangible User Interface (TUI) with reliance on multimodal Reality Based Interaction themes (RBI) [**23**]. At this stage, our objective is to enhance efficiency of parallel browsing by reducing the time required to successfully complete comparison tasks. Accordingly, we carried out a user study to investigate and compare our approach's efficiency and usability with those on a laptop.

2.2 Related Work

The drastic growth of using parallel web browsing features has been indicated and studied in research communities. Wenreich et al [**32**] has monitored a shift in user's web browsing behavior from single-path to several-paths web navigation. Balakirshan et al [**21**] have also concluded, through a user-study, that tab switching was the second most frequent browsing activity. Thatcher et al [**24**] and Huang et al [**17**,**18**] have additionally found a significant adoption of parallel web-browsing behaviour in their results.

A number of studies traced parallel browsing behaviour to different users' tasks. Such tasks include branching to different results from a search engine's results page [**24**], comparison of different contents [**21**], and web page backtracking and revisitation [**21**,**24**]. Moreover, the majority of available parallel browsing user studies focused on desktop web browsers [**17**, **21,24**].

Several research papers have also indicated different users' preferences in using parallel web-browsing features. Balakirshan et al's [**21**] work has shown that the majority of people prefer using tabs over windows. In their user study results, they also found that users thought tabs are quicker to load, faster to switch to and visually superior to windows.

Likewise, an important aspect of our proposal is the portrayal of web pages in virtual environments (VEs). Card et al [**25**] provided great interaction-insights in VE-based 3D web browsing. Their work included two parts: i) Webbook: 3D book in a VE, where the book's pages are web pages; ii) Web forager: an information workspace which groups various Webbooks. Other studies examined various metaphors, like depicting web pages as flat-rectangular objects in 3D VEs (as in an art gallery) [**26**] or web pages as virtual 3D world [**27**].

Challenges of interaction in 3D web browsing were mainly tackled in Jankowski et al's work [**28**]. First, they discussed important traits of 3D User Interface (3DUI) manipulation, and then proposed various web browser interaction techniques in 3D VE.

Lee et al [**29**] have examined interaction of 3D VEs in a semi-transparent screen, which combined inputs from hand gestures, a keyboard and a mouse. Their results indicated that users could greatly benefit from spatial memory in placing and retrieving 3D objects. Results also indicated users' preference of bimanual interaction.

Lastly, we essentially base our approach on RBI [**23**] themes. The RBI framework classifies user interaction with the real world into four different themes: 1) Naïve Physics: common sense knowledge about the physical world. 2) Body Awareness & Skills: awareness of people's own physical bodies and the skills for controlling and coordinating their bodies. 3) Environment Awareness & Skills: Awareness of the surroundings and skills to negotiate, manipulate and navigating within the surrounding environments. 4) Social Awareness & skills: awareness of other people within their environment and the skills necessary to interact with them.

The main concept of RBI relies and builds on users' pre-existing knowledge of the real non-digital world. Naïve Physics. As a result, we adopt RBI themes because of potential benefits in accelerated learning time, reduction in mental effort during interaction, and overall performance improvements. In addition, we base our concept of natural interaction based on RBI framework.

2.3 Problem Analysis

1. Screen Size

The amount of viewable contents, in web browser windows and tabs, is primarily determined by screen size. The smaller the screen, the more impractical and limited the view becomes. Thus, in the context of contents-comparison, usability and practicality of multiple windows and tabs are proportional to screen size.

2. Time Consumed in managing Windows and Tabs

A user study [**17**] found that at least 57.4% of users' browsing-time included tab switching. However, tabs were found to be ineffective in complex comparison scenarios [**21**], mainly because they lack side-by-side views. Thus, we concluded that the mentioned findings could indicate a certain amount of wasted time in using tabs. Moreover, we expect a further decrease in efficiency when multiple windows and tabs are both in use.

3. Limited Interaction

In our opinion, the amount of wasted time, in managing windows and tabs, is also a consequence of WIMP (Windows, Icons, Menus and Pointers) user interfaces. For instance, despite advances in interaction techniques, users still primarily use a pointing device to resize and arrange browser windows. We believe that emerging interaction techniques, like TUI or hand gestures, could improve interaction efficiency in parallel browsing environments.

4. Document Metaphor

Web pages' interaction metaphor extends the real physical world's document metaphor with interactive WIMP-based components. Emerging interaction technologies, like TUIs and AR, offer far more potent interaction patterns than what a document metaphor requires, especially in interaction flexibility and visual capabilities. In order to take full advantage of emerging interaction technologies, the web page metaphor has to be fundamentally redefined.

2.4 Our Approach

We have based our approach on earlier techniques that used 3D-objects which are textured with web pages [**23**, **26**]. We have chosen to portray web pages as rectangular-shaped 3D-objects, similar to the document metaphor. At this phase, we have mainly adopted this approach due to the shape's similarity to how web pages are displayed in personal computers' (PCs') web browsers.

In addition, we have used AR to render the 3D VE so that users would not lose visual contact with the real world. We have utilized fiducial markers, which are printed images that are easily detectable by a computer through a camera feed, to position 3D web pages in spatial registration with the real world. In user's view, web pages are rendered and positioned depending on the location and orientation of fiducial markers.

2.4.1 3D Web Browsing Task Taxonomy

Jankowski et al [**28**] have categorized interaction with 3D web browsers into two groups (These groups are illustrated in **Figure 3**:

1. **Web Related Tasks**
   Include tasks that are related to conventional web browsing tasks, such as locating information on a page, editing data and submitting information within web pages.

2. 3D Tasks
Cover tasks that are related to 3DUI interaction, such as object selection in 3D VE, control of user's view of the scene, as well as manipulation of an object's position in 3D VE's space.

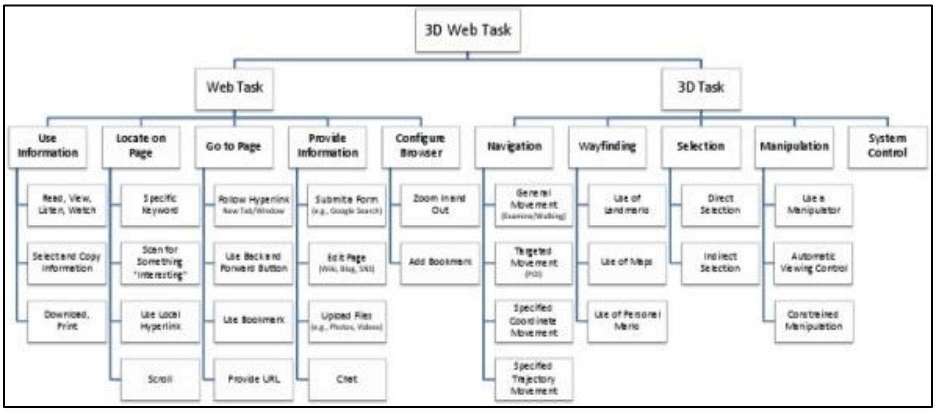

Figure 3: Illustration of Task Taxonomy (Taskonomy) of 3D Web Use (Junkowski et al [**28**])

We extend this taxonomy by including a third category:

3. Heterogeneous Tasks
Include tasks that simultaneously impact both web contents and 3D environments. For instance, upon conducting an online search, web pages that contain search results would be automatically aligned and positioned facing the user.

2.5 Prototype

The main hardware components of our prototype are illustrated in **Figure 5**. Our prototype also included a PC (in the background) for processing input/output and integration of different systems.

Moreover, the technical software architecture of the prototype contain the following core components:

- **Web browsers:** A WebKit [**43**] based web implemented using C# bindings and C++ programming languages. Web Browser instances are run as background processes and their visual output is rendered internally.

- **Augmented Reality System:** A group of libraries that contain different image processing, detection and tracking of fiducial markers in a video feed. In our prototype, we utilize Qualcomm's Vuforia [**40**] to achieve AR extended fiducial-marker based tracking.

- **Unity3D:** Unity3D is used to integrate all system components together. In addition, Unity3D engine is used to handle 3DUI, animation as well as user interaction in real time; essentially utilizing it to deliver the intended user experience.

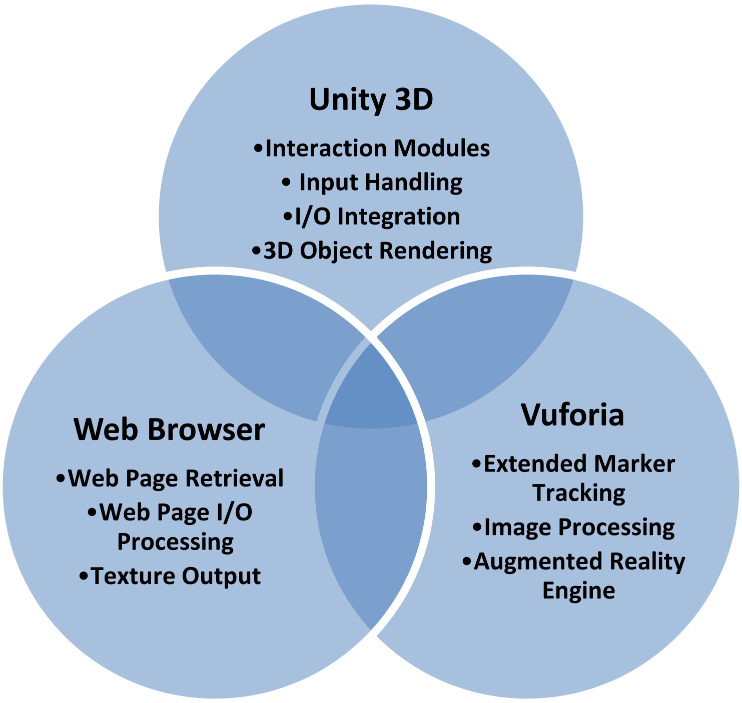

Figure 4: This figure shows the 3 core components in our prototype. Each of the components contains essential roles in the overall system. For instance, Vuforia is integrated for its' extensive image processing and marker tracking capabilities to deliver contents in AR. Similarly, the Web Browser engine is integrated to handle web related tasks, such as interacting and navigating to different pages as well as retrieving web contents. Unity3D is essentially utilized to govern, handle and integrate the all system components and their related user interactions.

In our prototype, the system initializes and interconnects the following components:

1- Web Browser instances are instantiated according to initialization configurations. The configurations determine the initial number of Web Browser instances, resolution, web page text sizes and other web related initialization attributes.

2- Vuforia and Unity are initialized by initiating camera feed and executing needed runtime libraries.

3- Each Web Browser instance's output is converted to a stream of images, directly from the backend framebuffer, which is then sent to Unity3D to be applied as textures for selected 3D objects.

Upon initialization, the following sequence of steps summarizes the flow of input from the user through our prototype:

1- When a user clicks with the mouse, mouse position is converted from 2D coordinates from the users' view, to 3D raycast on the 3D virtual environment using Unity3D's mouse raycasting. This step is needed as web browsers are presented as 3D objects in the real world using AR.

2- If a raycast hits the texture of web browser object, the coordinates of collisions on the texture are forwarded to the corresponding web browser instance.

3- The back-end Web browser instance converts the forwarded coordinates to click events on linked web page.

4- As these textures receive the web page stream from the frame buffer, the output of the click event is immediately reflected on the front-end's web browser textures.

Similarly, each keyboard event is forwarded to the selected web browser instance. The only difference is that input is forwarded based on selected web bowser instances. For example, a user would select a web browser instance, or a group of web browsers, after which each keyboard input is forwarded to the intended web browsers.

The advantages of using our mentioned approach is that it provides flexibility in binding textures to 3D models, since models can take any shape. In addition, input is totally segregated from each of the browser instances, so users can trigger simultaneous input on several web browsers. For example, users are able to scroll down web pages on a group of web browsers. We believe that group based interaction and flexibility of 3D models are essential building blocks for future investigations of our approach.

Our chosen set-up reflects the mentioned 3D web browser interaction taxonomy in the following manner:

1. Web Related Tasks: We used a wireless keyboard for text entry and a mouse as a pointing device due to user-friendliness and common usage. Users were able to interact with web pages in the same way as in common web browsers. For example, users could scroll up or down in a page with the scroll wheel or click hyperlinks with the left mouse button…etc.

2. 3D tasks: To manipulate the web pages' position, orientation and proximity, users had to physically modify the equivalent properties of fiducial markers (**Figure 6**). This set-up allows direct and easy-to-learn interaction, as it builds on users' previous knowledge of real world's properties [**23**], thus, directly extending the four RBI themes.

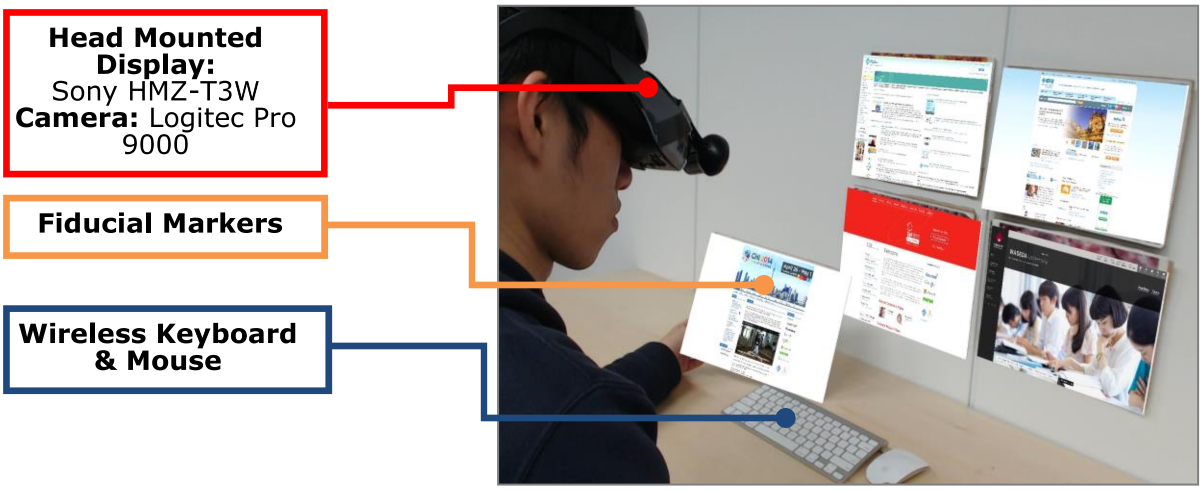

Figure 5: A participant using our prototype with fiducial markers on the wall and in the user's hands.

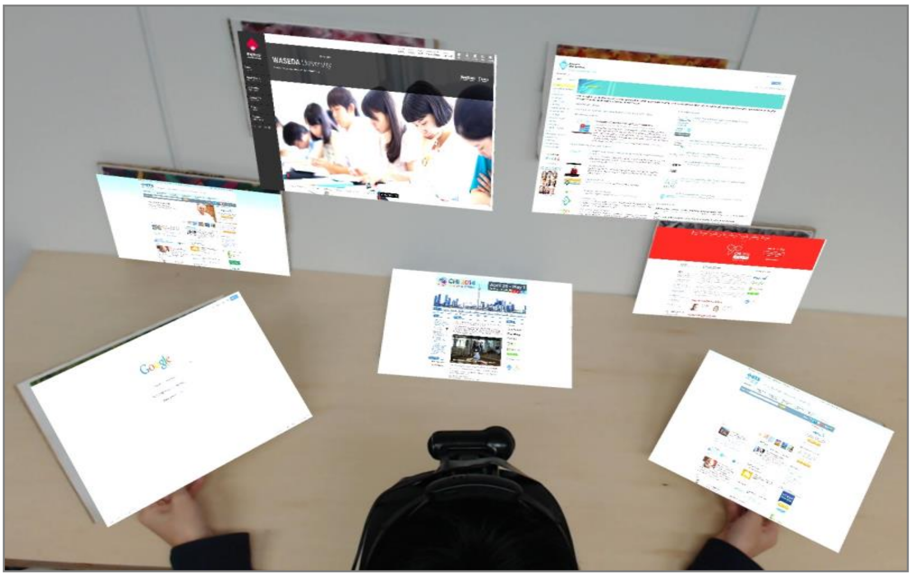

Figure 6: A user physically manipulating position, orientation and proximity attributes of fiducial markers with his hands. The fiducal markers' attribute-changes are simultaneously applied to web pages in AR.

2.6 User Study

To evaluate our approach, we have designed a task that required comparisons of 3 or more web pages to succeed. The goal of the experiment was to study and assess whether our system, in comparison to a laptop, would shorten the time taken to compare web pages.

Accordingly, we have developed 12 web pages, each contained 23 unique camera attributes like resolution and weight. Each of the web pages was unique in their attribute values, arrangements as well as graphic designs. We also recruited 10 university students (9 Males, 1 Female, between the ages of 20 and 35 years). Participants reported using multiple browser windows and tabs with an average of 6 hours daily.

The comparison task required answering 7 questions regarding 6 cameras, with trials on both a laptop and our prototype. Before the experiment, each of the participants was briefed about all of the camera attributes and question types. Moreover, participants had to practice for approximately 4 hours spanning over two days. Practice sessions included a similar shorter version of the comparison tasks, with guided and unguided usage. Since we opted for an in-between user study, half of the users started the user study on the laptop's tabbed web browser, and the other half of the users started on our prototype.

2.7 Results

After the user study, participants took a questionnaire (5-point Likert scale: 5 = strongly agree, 4 = agree, 3 = not sure, 2 = disagree, 1 = strongly disagree) and a 30-minute interview to measure different aspects of our system. First, participants responded to *"How close our comparison tasks are to participants"* daily browsing tasks" with an average score of **4.37** (**SD=0.354**). In our opinion, this score reflects a close resemblance to participants' daily browsing tasks.

In terms of performance (**Figure 7**), with our prototype, 70% of participants achieved an average of 21.37% decrease in the time needed to complete comparison tasks.

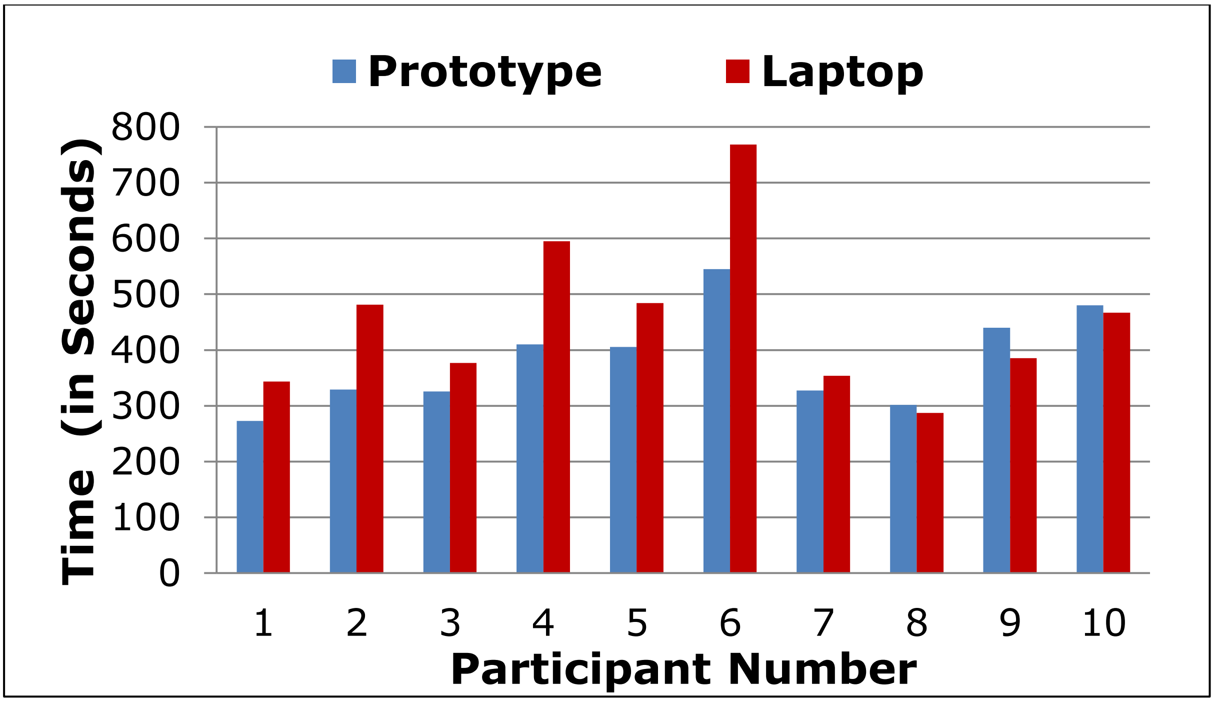

Figure 7: This diagram illustrates completion time of comparison-task for the successful 70% (Participants 1 to 7) of our participants.

We have carried out deeper statistical analysis on our data by calculating confidence intervals (**Table 1**). The confidence intervals provide evidence of our approaches potential to reduce the amount of time required for the comparison task. The upper and lower bounds indicate the amount of decreased time (in seconds) for our participants if they would accomplish the same task on our prototype (When compared to the PC).

Alpha	Upper Bound	Lower Bound
0.05	-23.711	-1.80
0.1	-21.633	-3.879
0.15	-20.377	-5.134
0.2	-19.453	-6.058

Table 1: This table shows confidence intervals of the amount of decreased time (in seconds) achieved with our prototype in comparison to the performance time on the laptop.

Among the participants' performances on both the laptop and our prototype (**N=10**), there was a statistically significant difference between the performance on both systems. The time on task with the laptop (**M= 454.258**, **SD= 134.677**) and on the prototype (**M=383.760**, **SD= 82.599), t(90)= -2.434, p ≤ .05**. Therefore, we reject the null hypothesis which states that there is not a true performance difference between the two set-ups.

Furthermore, participants' comments indicated three positive characteristics of our approach:

- **Flexibility of Movement** – In comparison with the stationary laptop, participants mentioned feeling "*free*" since they could interact with web pages in different postures (e.g. standing or sitting) and almost anywhere within the trial's room. Additionally, we noticed an overall increase in the participants' physical activity as they progressed in using the prototype. Participants comments included: *"It was good in the aspect of freedom in organizing windows*". Another participant also added: *"Overall, it has a great degree of freedom, e.g. ease of movements and interaction while sitting or standing"*.

- **Ease of Learning** – Participants' familiarity with RBI themes, the keyboard and the mouse was effective in decreasing the learning time significantly. One participant commented on ease of learning: *"it took 15 minutes to master"*.

- **Reduced Memory Load** – 40% of all participants have reported that, during camera comparisons, they had to remember more information on the laptop than on our prototype. Participants justified this tendency by their ability to rely on spatial memory to arrange and locate web pages and related contents. Moreover, this observation is consistent with previous studies [**29**].

Likewise, participants specified three shortcomings:

- Participants would often lose or misplace the mouse due to their physical movements. As a result, participants wasted some time searching for the mouse after losing it (Average is 4.5 seconds).

- The results of the 30% underperforming participants showed a generally positive progression in performance (**Figure 8**). We believe that these participants may have needed more time to surpass their laptop performance. However, we have yet to deeply analyse possible causes of underperformance.

- All participants have reported feeling dizzy and eye-fatigued while using the Head Mounted Display (HMD). Participants have rated both "*Text Readability*" and "*Usage Comfort*" on the HMD with an average of 3.50. Moreover, approximately 50% of all participants scored 3 or less in the two stated aspects.

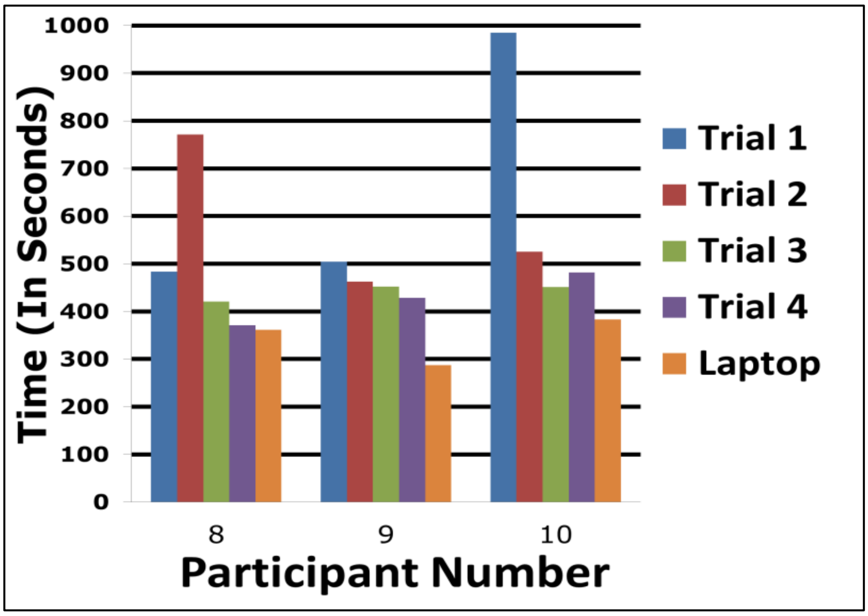

Figure 8: This diagram illustrates the 30% underperforming participants' progression in trial-times on our prototype against their trial time on the laptop.

In the end, participants rated "*simplicity and ease of use*" with **4.36** (**SD=0.212**) and "*whether or not our prototype would support their daily browsing activities*" with **4.22** (**SD=0.285**). Finally, participants rated their overall satisfaction with the prototype with a score of **4.36** (**SD=0.094**).

Despite the existence of the above shortcomings, we concluded that our concept and approach were generally well-received by the participants. In addition, the positive performance results were encouraging to further investigate possible potentials of our approach.

2.8 Future Work

In the future, we intend to expand our work to cover broader linear and parallel browsing requirements. We will pursue two more directions: 1) Metaphors and 3DUIs (**Figures 9** & **10**); 2) Varied forms of RBI themes. Throughout our future work, we intend to continually measure effectiveness and progress of our approach with long and short user-studies.

Figure 9: A physical cube-shaped object that is textured with web pages in each side (with AR). Users can physically rotate or manipulate the cube to view different webpages in every side.

Figure 10: AR web browsing workspace, containing different 3D objects that are textured with web pages.

2.9 Project Conclusion

Regardless of the projects' promising results, there were different obstacles that forbid daily adaption and complete realistic implementations. These shortcomings are mainly related to the following aspects:

- **Technical Difficulties:** Users were not able to utilize our prototype for extended periods of time. Participants could wear the HMD for a maximum period of 20 minutes, after which they needed to take a short break due to the HMD's heavy weight and discomfort. The HMD also caused participants to feel eye fatigued and was incompatible with prescription glasses.
- **Scalability:** Since we utilized techniques based on tangible interaction, it was not possible to scale up the system with conventional tangible methods. If we bind each of the digital objects to a definite physical objects, it would not be feasible to have more objects than the number of

currently available physical objects. As a result, we would have to investigate methods to scale up our approach to handle large number of browser instances.

- **Mobility:** Tangible interaction requires the existence of physical mediums to interact with computers. Consequently, Tangible interaction is suitable for situations where a user is mostly stationary in one location (i.e at the office), it is not feasible for users to carry physical artifacts, while commuting, just to interact with computers.

2.9.1 Encouraging Outcomes

2.9.1.1 Ubiquity and Mobility
Overall, all participants reported feeling free to move and arrange their digital workspace exactly in the same manner as their physical workspace. Participants felt that they could go around the room freely without having to physically transfer a device or attach a monitor to view web pages.

2.9.1.2 Natural Interaction
Participants reported that the required learning period to master using the prototype was minimal. This is very expected as RBI was embedded to model the interaction with web pages. Hence, users did not have to learn much as interacting with the prototype was similar to their interaction with regular paper.

2.9.1.3 Invisibility
The workspace was totally empty of any digital contents (except in cases where input devices where needed). Our approach strives to retain simplicity of our surrounding environment, and as such relies on the HMD to relay information proved to be an effective method to provide visual information without any apparent computer devices.

2.9.1.4 Performance Efficiency
The interaction theme was specifically modelled to parallel-web browsing needs; i.e simultaneous views, quick page formation, manipulation, grouping and sorting of web pages. This has resulted in direct performance impact that WIMP based interfaces and limited visual screens are not able to sustain, neither while stationary nor mobile.

2.9.2 Outcomes Requiring Deeper Investigations

2.9.2.1 Mobility and Tangible Interaction
Mobility of our prototype was mainly bounded by technical and interaction issues. In terms of technical difficulties, there are not high fidelity HMD displays that could be deployed to uncontrolled mobile situations. Most current HMD are either heavy in weight, need direction to PC connection or offer humble visual fidelity. In addition, tangible interaction essentially relies on physical objects that shape physical interactions with computers. While tangible interaction proved to be successful in situations where a user is static at a certain location, like the office or home, mobility remains a huge challenge for mobile tangible interaction. The ability to take advantage of tangible interaction insights is crucial towards extending our approach.

2.9.2.2 Scalability
In our developed prototype, users could interact with 6 pages corresponding to 6 tangible objects. Related literature indicated that the average number of open web-pages of users exceeds this number [**17,18,20,21**]. Therefore, a method to scale up the number of pages a user is able to open has to be investigated to further realistically reflect demanding usage needs in web browsing.

2.9.3 Interaction Insights
As users approached the prototype, they were intrigued by the set-up and arrangements of objects, since the set-up did not resemble a typical computer at all. During the orientation sessions, participants were given the time to interact naturally with our prototype, and they attempted to experiment with

tangible interaction via different methods. For example, some participants attempted to touch the 3D objects, while others tried to physically align fiducial markers next to each other to see how this arrangement would affect the experience. Some other participants also experimented with gestures and hand movements to interact web pages tangibly. It is very important for a system to be corresponding to exploratory aspects by offering flexible interaction patterns, similar to real world's interactions.

In addition, each of the participants essentially had a unique interaction experience with prototype. While some users preferred to be seated, others preferred standing or a combination of both at different stages. Some participants laid out the fiducial markers either on the wall or on the table, while others mainly held the fiducial markers with their hands.

Uniqueness of interaction was also extended to the tasks, as there has been evidence of distinct tangible grouping and sorting preferences. As for grouping, Participants' gathered similar webpages by physically stacking fiducial markers above each other's; forming a book-like entity that could sequentially be flipped through to view different webpages. Moreover, participants spatially grouped webpages based on specific attributes of interest. For instance, a participant would use the left side of the table for cameras of type 1, while the right side of the table would be dedicated for cameras of type 2. Other participants have additionally utilized similar techniques to group items explicitly on the wall or in combination with the table. This phenomenon has occurred dynamically with respect to various properties of task requirements.

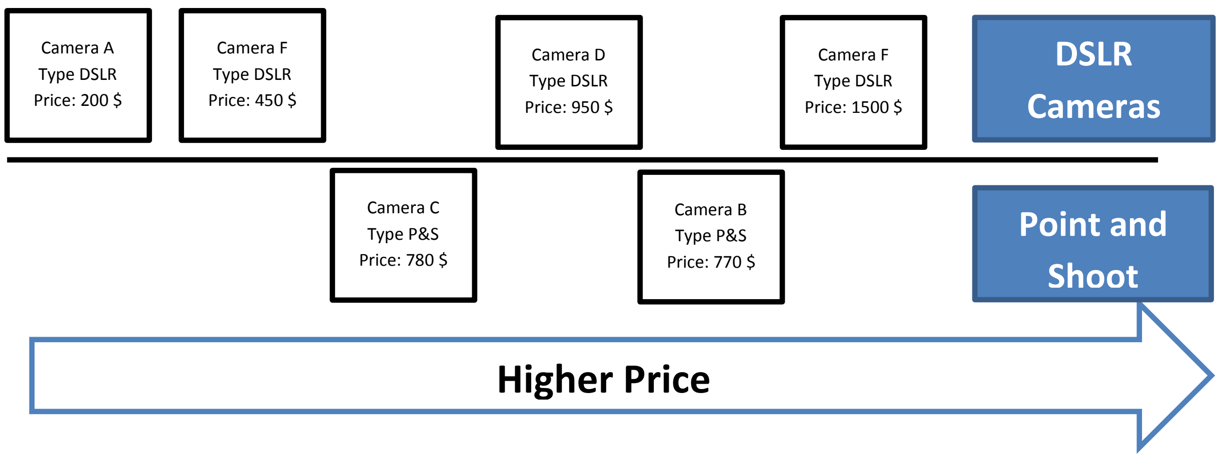

Figure 11: This figure illustrates how users utilized sorting and grouping techniques to physically classify web contents. The upper lane contains web pages of cameras of type DSLR, while the lower lane contains web pages of cameras that are of type Point and Shoot (P&S). Cameras were arranged horizontally in ascending order (From left to right), where left most resembles the camera with lowest price.

Furthermore, Participants demonstrated a number of tangible sorting techniques. Some Participants physically arranged fiducial markers linearly, in ascending or descending orders, on the wall or/and the table. Some participants preferred stacking fiducial markers above each other to reflect ascending or descending orders of a definite attribute. Participants have also maintained both vertical and horizontal sorting alignments of fiducial markers. Finally, in order to maintain webpage-groups, a number of participants carried out a combination of grouping and sorting techniques. For example, a participant would sort cameras linearly using two lanes instead of one, with each lane corresponding to a specific group (**Figure 11**). By merging sorting and grouping techniques, participants were able to maintain both the groups' exclusions and flexibly execute sorting tasks.

We believe that all of the mentioned aspects of interaction point out unique interaction features that essentially reflect perception patterns and sensory preference, rather than usage efficiency, effectiveness or ideal intended usage. Moreover, exploratory characteristics that accompany tangible interaction and augmented reality have been well documented in previous literature. Research [**24**] has indicated that RBI themes encourage experimentation and discovery, as users interact with tangible objects in similar fashion to the real world, users feel stimulated to experiment with these objects and observe results. Based on our prototype, participants essentially were constrained by specific usage models that were imposed as part of the designers' vision towards ideal interaction. We feel that our system lacked the flexibility of correspondence towards the users' natural exploratory behaviour with tangible objects. The exploratory behaviour principally enables users to forge unique interaction paradigms with real world objects from the users' own and distinctive perspective. To conclude, we believe that the interface's ability to flexibly cope and dynamically correspond to users' interactions and needs is most crucial to improve the users' experience.

As a result, the above conclusions steered the project to further pursue aspects of mobility, additional interaction methods as well as further methods to support parallel web browsing requirements. As these problems are not restricted to a certain usage scenario, it is important to generalize our approach for it to be applicable in other tasks, contexts and to reflect further user-centric requirements. Hence, for our approach to be further investigated, intensively analysed and generalized, mentioned issues are abstracted and put into context of mobile daily use (In the next chapter).

3 User-Defined Multimodal Cross-Device Interaction

3.1 Introduction

Cross-device interaction has long been studied in numerous research literatures and projects. Many of previous literature emphasized the importance of cross device interactions as a mean to better achieve our tasks by further utilizing our currently available devices [**33,34**]. Despite advances in interaction with current devices, current interaction paradigms have different shortcomings that forbid users from making the most out of their devices. For instance, cross device information sharing and synchronization is currently done via ad-hoc or infrastructure based services, like Bluetooth sharing or cloud services, respectively. These services remain lacking in terms of ease of use, simultaneous, instantaneous dynamic access and utilization.

With the advent of Head Mounted Displays (HMD) increasing role in the modern lifestyle, it is necessary to understand how cross device interaction is situated in the context of HMD. Different research projects examined how HMD based Augmented Reality (AR) could play vital roles in enhancing task performance on hand held devices and wearables. However, in professional work spaces and daily productivity aspects, we believe it is very important to understand how HMD based AR can weave itself with current and future productivity based devices, such as laptops, desktops and tablets, especially for productivity related contexts.

Naturally, HMDs will be common in the upcoming years. Part of the users' HMD view of the real world includes laptops, tablets, smartphones, and other devices. However, each of the devices' interaction methods is almost completely segregated. For example, suppose a user would like to instantly transfer an image from a smart watch to a laptop, make some modifications to the image and later view it on a wireless HMD. Currently, the mentioned simple task would not only take a lot of time to plan and establish communication among devices, but users might also need to resort to other unrelated services and methods, such, as emails, remote-access or cloud services. In the context of the above scenario, current interaction methods demand excessive planning and execution time besides needed knowledge and access to other services and applications.

Additional studies also points out that one of the main goals of simultaneous muti-device use is users believing they would achieve better task performance or I/O facilitation. Nevertheless, the current generation of devices operates separately from one another, especially in terms of interaction, coordination, and task context. As a result, users must coordinate, prepare and orchestrate different devices, their connectivity and interaction styles to accomplish their tasks. Accordingly, current devices demand excessive amount of time and effort to coordinate their connected activities.

Moreover, Current cross-device interaction methods are inflexible; dynamic cross-device multimodal interactions are not possible; to form and reform different combinations of input and output (I/O) paradigms. In continuation to the previous example, a user may want to use a trackpad of a laptop with the smartwatch, or use the smartwatch's touch screen to interact with AR contents. Moreover, if a user needs to dynamically switch usage of trackpad to control other devices, such as another laptop or a tablet, it would not currently be possible without huge sacrifices in time, effort and functional-fidelity. The goal of using many devices is that they should support the users in accomplishing their intended tasks. In order to successfully support users' dynamic and ubiquitous life styles, we believe that input and output devices must be dynamic and ubiquitous. Nevertheless, completely dynamic multimodal cross-device interaction is not possible yet.

A user's task should be the canter of cross device interaction, as such; all devices must support the users to accomplish their tasks. The current state of devices is completely the opposite, as each device acts in isolation from one another, leading to users having to support their work through careful arrangement and organization of devices to accomplish their needed objectives. We believe that all input and output methods must be grouped together to support the user tasks; task oriented instantaneous dynamic and multimodal interaction is, and will be, a necessity in our daily lives.

3.2 Preliminary Analysis

3.2.1 Shortcomings of Current Usability Designs

Most current devices demand an excessive amount of time to set up, configure and use in specific contexts and tasks. A lot of previous research, such as [**33,34**], have looked at various aspects of multi-device usage, whether in terms of techniques to support users' activities or diary studies to understand current cross-device user-behaviour. Nevertheless, a minority of studies examined how HMDs is situated in the context of daily cross device interaction.

In our analysis, we look at three different limitations that we intend to thoroughly investigate:

A. Device-Dependent Applications

Current applications are tightly coupled to specific hardware and software architectures (**Diagram 12**). Some applications might function on specific CPU, like ARM, while others are only compatible with x86-architecture. In addition, some applications are exclusively compatible with specific Operating System (OS), like Windows OS applications. Many applications also combine hardware and software based restrictions, demanding very specific set up to function, like Apple's iOS applications.

From a user perspective, there are a number of work-arounds to utilize applications across devices. First, there are already a number of cloud services that could assist in data synchronization across devices. Other solutions are Web based applications that execute applications in web pages, though, these implementations lack in terms of interaction responsiveness and input devices integrations as most rely on WIMP interactions [**31**]. Additionally, simultaneous and dynamic switching and utilization among devices of diverse hardware and software architectures is currently impossible. We believe that applications should be boundless, flexible, form depending on context, available hosting-architecture and, most importantly, users' needs and preference.

B. Dispersed User Experience

In current devices, regardless of the unity of a user's tasks (**Diagram 12**), he/she would interact with each device in seclusion from other devices. For example, suppose a user would like to compose a document based on different references. A user would utilize a laptop to compose the document and use a tablet to access and navigate through references. A typical usage would be using the laptop's keyboard to insert text, while concurrently using the tablet's touch screen to navigate through references. Since, both devices are unaware of the user's task, there would be a time wasted in switching use of I/O to interact with each device, visual accessibility issues to gaze at different screens, and flow of data (Such as when attempting to copy a reference from the tablet to the laptop). The lack of coordination among devices makes the user's interaction scattered among devices to accomplish the tasks, rather than focused on the task with disregard to devices.

Diagram 12: This diagram illustrates the relationship between users' actions and the intended tasks. Users attempt to accomplish different tasks by interacting with different devices .A task might be accomplished with one or more devices. However, the user attempts to utilize different I/O options, hardware capabilities and connectivity options to accomplish their tasks. Interaction with each device, specifically the applications' user experience, remains separated.

3.2.2 Shortcomings of Development Approaches

Current interaction experiences are modelled by either user experience designers or application developers through various development methodologies. Yet, the issues with development approaches can be summarized in the following:

A. Developer Reliant

Nowadays, the majority applications get constant enhancements to their user-experiences through software updates. However, a deployed user experience might not, if not totally, suit users' needs or preferences. As a result, developers tend to gauge market requirements based on development cycles to investigate new user requirements (**Diagram 13**). However, upon discovering a user requirement, the possibility of having a feature implemented depends on various factors (**Diagram 13, phase 2**). Crucial deciding factors include feasibility, effort, time, in addition to essential financial and monitization considerations that affect an implementation of user requirements. Consequently, a number of user requirements would be disregarded for financial or feasibility or other aspects.

This domination of developer-reliant interaction design has its' roots in software engineering practices and methodologies. Software engineering methods, like SCRUM [**35**] or Test Driven Development (TDD) [**36**] are quite successful for developing needed functionalities that closely correspond to user requirements. Though, within the context of user experience, these methods lack in responsiveness and generalizability of solutions [**41**].

For instance, in User Centric Design (UCD) methods, the feedback of the end user sample is statistically taken into account and generalized for the intended interaction design. Statistical methods disregard two important aspects: First, they neglect the views of the majority of potential users who are not included in the statistical studies. Second, these methods do not emphasis the vigorously dynamic nature of interaction; such as with changeability of human behaviour, physiological and psychological preferences, as well as situational and contextual needs, which all vary over time [**41**].

B. Minimal end-user involvement:

While a small group of users could be involved in initial design of the interaction experience, the majority of the users are minimally involved, if at all, in the design process. Many requirement gathering techniques, like personas [**37**], tend to focus on specific and significant sample of users. The main aim of such techniques is generalization of requirements of the minority of users to suit the majority. As a result, in large multicultural and dynamic environments, it becomes extremely impractical to conduct continuous and in depth user studies to model interaction preferences of all users.

C. Rigidity

In practice, the design of a users' experience, based on current development practices is problematic. Current development practices assume users would adapt to intended interaction after deployment, and if faults exist within the user experience, they would be patched later on. After deploying an application, the user experience is rigid and inflexible; it is not possible to fundamentally customize and personalize the experience per user's distinct aesthetics preferences, functional needs, contextual and personal requirements without essential changes to the applications source code. Even when assuming developers would constantly improve the user experience based on the dynamic user requirements gathering techniques, such implementation of a change could require a period spanning from days, to months and sometimes years **(Diagram 13**, **Phase 1** to **Phase 5)**.

It is impossible to carry user studies with all intended users, especially when developing products for a massive number of end users. Although statistical methods are successful for small to medium scale user experience development, these methods fail to appeal to each and every potential user; essentially due to distinct and dynamic user differences and preferences as well as contextual requirements [**41**]. Thus, iterative approaches are often adapted to re-evaluate usability traits or discover new requirements. Nevertheless, iterative methods restrict the user experiences' from generalization across cultural and contextual variations, as well as physiological and psychological requirements of users, mainly since the end product would be a reflection of a constrained user sample in a definite time period. Thus, relying on developers and standard design methodologies is impractical.

In conclusion, standard methods of application development are not suitable for massive HCI experience design, mainly for aspects of restricted agility, responsiveness to user needs and generalizability. Consequently, a new approach must be investigated to better bridge the gap in massive scale interaction design.

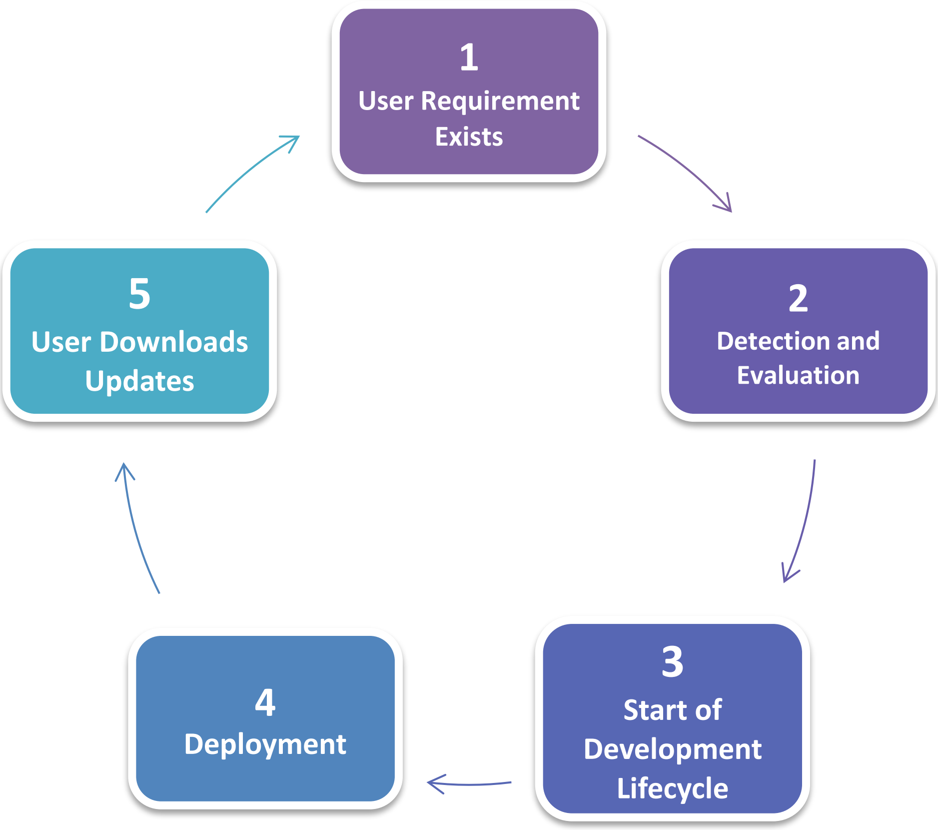

Diagram 13: This diagram illustrates the different phases of user-experience's development lifecycle. The time between the existence of a user requirement to the time a user downloads an update could span from days to months or years, depending on detection and evaluation of a requirement and complexity of feature among other contributing factors.

3.3 Vision of HCI

3.3.1 User Defined Interaction

Our previous work [**31**] indicated that the interface could not dynamically cope with the varied interaction expectations from users, which ultimately lead to the opposite; users had to cope with a specific interaction style. Evident by the current state of computing, coping with specific devices interaction styles could possibly lead to better efficiency. Nevertheless, based on user insights and promising performance gain in our previous work, we are very intrigued to investigate the opposite approach. By enabling devices to dynamically correspond to users' interaction needs, we believe that this approach would significantly lead to an overall superior user experience, particularly in terms of efficiency and user satisfaction.

Previous research, essentially in Adaptive User Interfaces [**41**] had already indicated that distinct individual differences among users, their unique usage contexts and requirements, cannot be sufficiently fulfilled with typical application development approaches. Therefore, we extend the abstract concept of Adaptive User Interfaces; by introducing user induced adaptability of a user experience as a whole. As a result our concept of user defined interaction is the users' ability to simultaneously model interaction to reflect dynamic physiological, psychological and contextual requirements, with the overall goal of supporting user's task.

Accordingly, we can classify characteristics of the user experience into two categories:

1. **Functional Characteristics:** Factors that affect direct functionalities of an experience, such as triggering actions, initiating or modifying processing logic and data flow.

2. **Aesthetic Characteristics:** related to color, shape, motion and beauty aspects of an experience. These elements are more related to personal taste, preferences and comfort towards certain artistic aspects.

Further classification of our approach's user experience is illustrated in **Diagram 14**. This diagram shows where a user is able to define the interaction towards an application (composed of internal functionalities). Our approach essentially extends the concept of separable user interface [**42**], where an interface can be separated from the internal execution of an application. We broaden the concept to deliver a user experience that is defined by the end user. Therefore, an application, or a group of application, can be effectively coordinated to support a user's task. In the other hand, interaction between the user and the internal functionalities of applications is totally defined by the user within the context of chosen task.

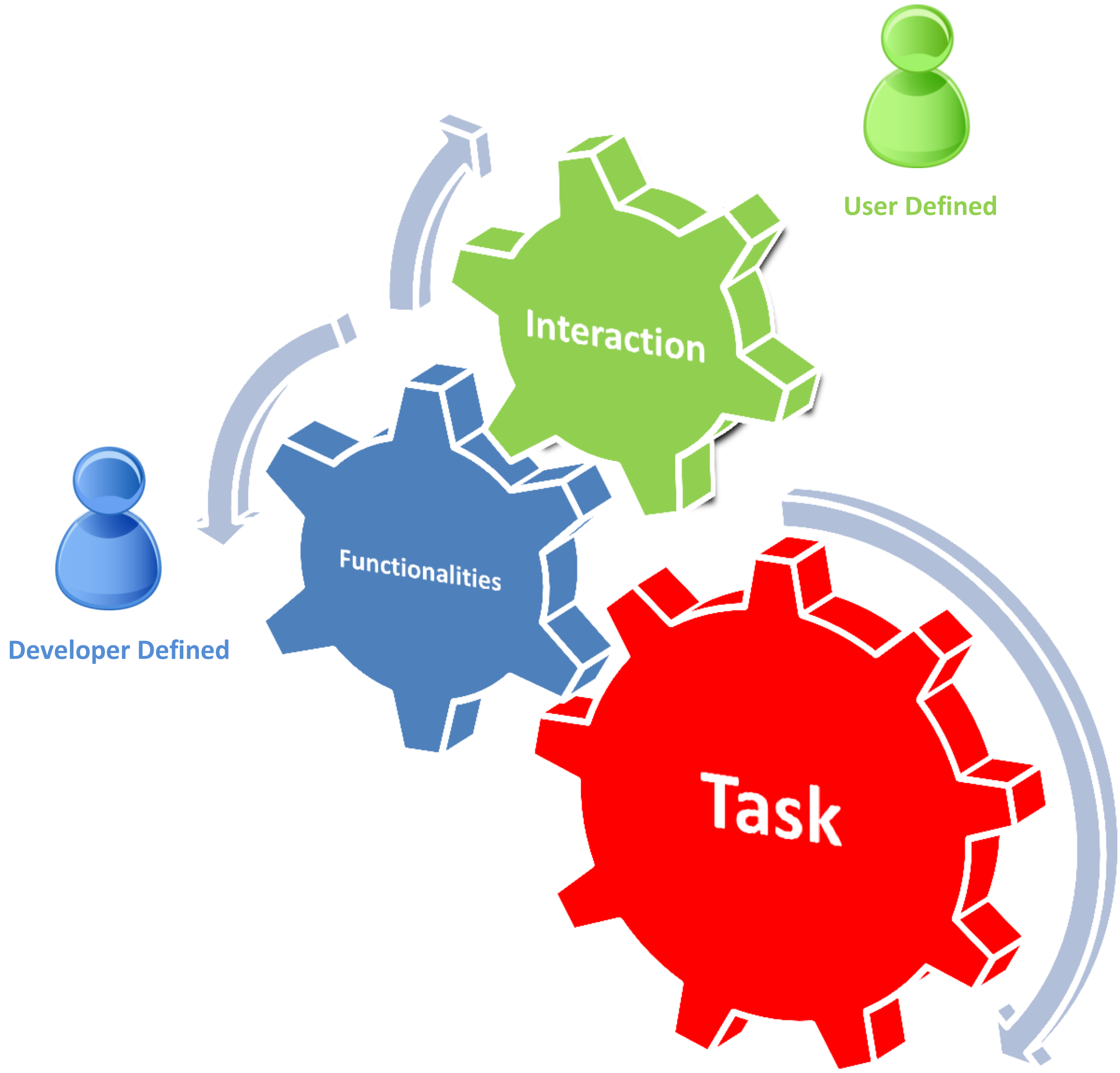

Diagram 14: This figure illustrates the abstraction layers with their corresponding identifiers; Interaction which is defined by the end-user, Functionalities which are defied by system builders (Developers or programmers…etc), and Tasks which correspond to the overall goal that a user is attempting to accomplish by utilizing a group of functionalities.

In addition we believe the following user-oriented interaction attributes are crucial towards defining a dynamic user-centric experience:

- **Input Mediums:** Defines which input method to performs an action within the users' experience.
- **Action Type:** Defines which action, or series of actions, upon receiving specific input.
- **Output Mediums:** Define how output medium should correspond to each action type.

Upon defining the three mentioned traits, we believe a user experience would be flexible to cope with the dynamism of user needs whilst still keep core functionalities within the realm of developers.
As such, this relationship is illustrated in **Diagram 14.**

3.3.2 Abstraction of Interaction

In order to achieve responsive user defined interaction, instantaneous communication among all devices must be abstracted, regardless of technical compatibilities. Such abstraction translates input streams, to a number of command classes that can easily be attached to and trigger various actions, which could finally be connected to different output mediums of the experiences. As a result, abstraction is needed in both input and output streams. The concept of user defined interaction is briefly illustrated in **Diagram 15**.

Therefore, abstraction is needed in two essential layers:

1. **Abstraction of Devices**
   Where devices hardware and software architectures must be abstracted through a unifying layer that exposes a devices capabilities to the user experience. As such, each of the devices that form the user experience must expose three aspects: **A)** Input Devices. **B)** Output Devices. **C)** Processing Capabilities.

2. **Abstraction of Communication**
   Communication among devices must be defined through abstract set of commands that can easily translate different input-device spaces to corresponding actions on the receiving ends. As such, a command is defined as any group of instructions that intend to cause an action. For instance, in a laptop, when a user moves the mouse towards a certain direction, a command is sent to the pointer to move in a certain translated speed and angle based on the swipe's physical attributes. Moreover, to further decrease the gulf of execution, it is better to minimize the gap between the target task and users actions [**38**]. Hence, an input device's commands are translated to user defined actions. For instance, tapping a the smartphones touch screen would send a command that triggers a user defined action, such as maximizing a window of an application or executing certain logic.

3.3.3 Cohesiveness of Interaction

Dispersion of interaction among various devices, that each execute applications in seclusion from one another, is an issue mainly caused by variance in software (including OS), and hardware, and separate physical existence. Cohesion of interaction aims for continuity of existence of the task-oriented user experience, beyond a devices hardware and software restrictions.

Similarly, to enable the user to have a continuous interactive experience, the status of execution, or execution itself, must occur beyond definite devices. In this manner, a task can still be accomplished regardless a device's physical availability, capability or compatibility with the chosen task. Accordingly, a device or a group of devices would be able to continuously support the user in accomplishing intended tasks regardless of mentioned restrictions.

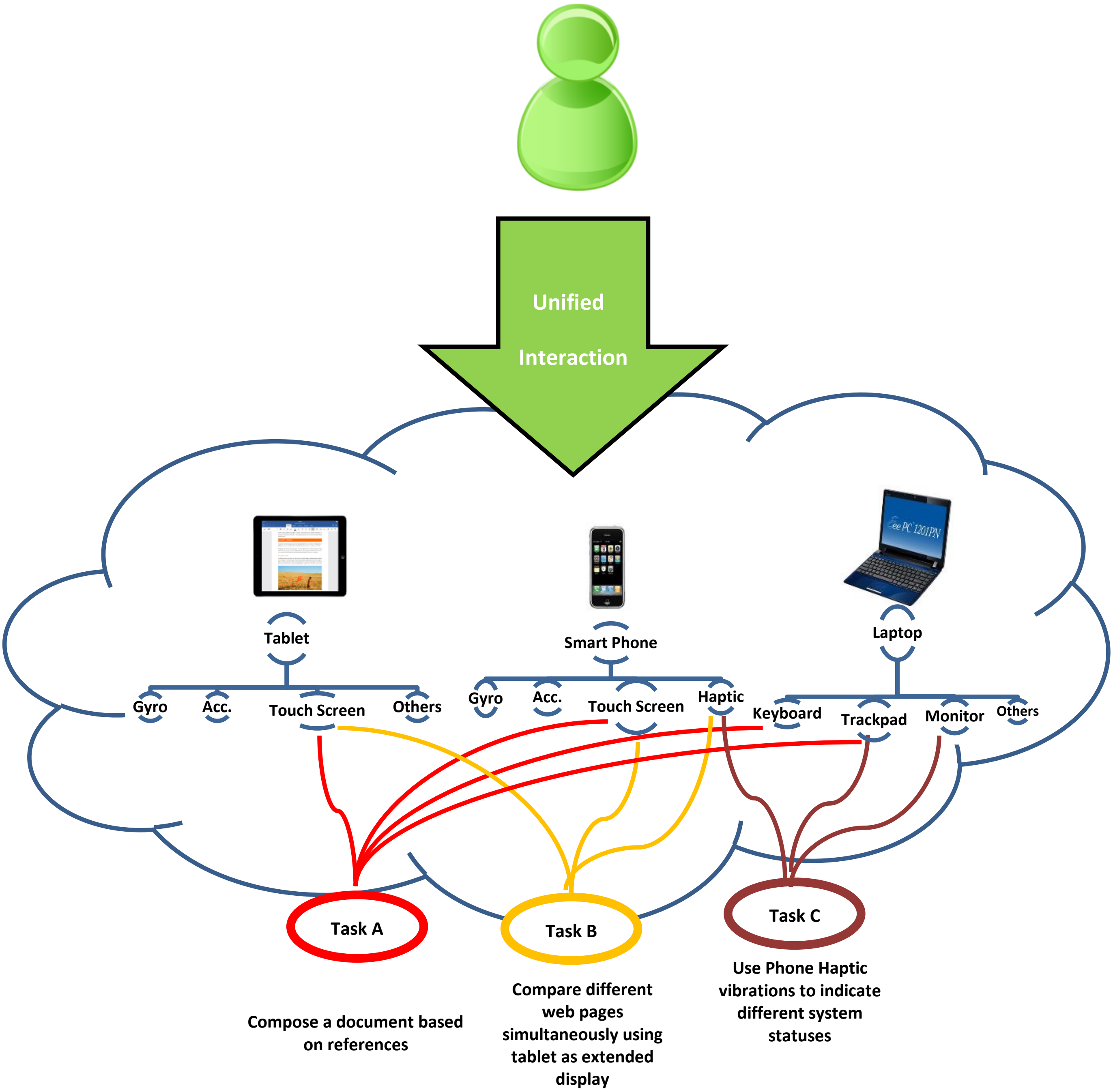

Diagram 15: This diagram illustrates our approach towards user-defined interaction. Users are able to choose any combination of input and output devices to accomplish their desired task. With I/O abstraction, a user can dynamically build a personalized user experience based on what they see fit to correspond to their requirements. The set of I/O is also dynamic, as the arrangement of I/O is instantaneously changeable.

4 Conclusion

Our previous work has led us to draw a number of deductions regarding our proposed approach's applicability and impact on daily life. The project has provided evidence that AR and tangible interactions could play a larger role in our daily life, not solely for their novelty or realism factors, but for actual performance and efficiency gains in everyday activities. The mentioned characteristic is specifically critical for the success of our approach; as it implies direct contribution to leveraging our everyday efficiency in accomplishing tasks.

Moreover, our results indicated a strong preliminary potential of emerging interaction techniques to promote healthier lifestyles. Since mentioned interaction paradigms enabled users to feel unconstrained to move and interact with digital entities more efficiently, we believe that further selective utilization of physiological abilities to interact with computers is essential in both performance and health gains. However, further analysis of current research in adjacent fields of research, such as ergonomics and human factors, is very vital towards maturing our approach.

In the future, based on our vision of HCI, we intend to further focus on a number of aspects regarding our approach. As wearables play a larger role in our daily lives, we believe that the need to support the humans' natural attributes, abilities and capabilities are essential to the future generations. We believe that a human centric approach towards computing is of most importance in the coming decade, as novel interaction keep emerging in both academia and the industry, there is a lack of concrete traceability between the physiological and psychological attributes and corresponding HCI design principles. We believe that mentioned traceability framework would significantly contribute to steering and governing HCI to better suit human nature, rather than impose on it. In the end, we strongly believe that the existence of mentioned framework would guide and yield better researchers and effective design principles, methodologies and traceability to human-beings, which would consequently have significant positive impact on our life.

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