Work-In-Progress Technical Report: Designing A Two-User, Two-View TV Display

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ABSTRACT

This work-in-progress paper previews how we can design interfaces and interactions for multi-view TVs, enabling users to transition between independent and shared activities, gain casual awareness of others' activities, and collaborate more effectively. We first compare an Android-based multi-user TV against both multi-screen and multi-view TVs in a collaborative movie browsing task, to determine whether multi-view can improve collaboration, and what level of awareness of each other's activity users choose. Based on our findings, we iterate on our multi-view design in a second study, giving users the ability to transition between casual and focused modes of engagement, and dynamically set their engagement with other users' activities. This research demonstrates that the shared focal point of the TV now has the capability to facilitate both collaborative and completely independent activity.

INTRODUCTION

The TV is often a social medium, however its use is often supplemented or entirely supplanted by other devices (such as laptops, tablets and phones), for multi-tasking, co-viewing or private viewing of content. It is this rapid uptake of other displays and devices which confirms a fundamental problem of the TV: shareability. We use TVs because they offer large, accessible, high-resolution displays which enhance our media consumption experiences. However, this naturally disposes users against sharing the display: split-screen and picture-in-picture approaches are inherently sub-optimal, often obscuring part of one picture in order to provide another of poor legibility/size, denying dedicated use of the display to each user. Additionally, they offer no privacy considerations. Personal devices circumvent these issues, guaranteeing the user full use of a semi-private display. However the phones, tablets or other devices being used are often inferior to the TV in some important respects, for example, in terms of size, casual accessibility to others in the room, and socialization. Significantly, not every user in the room may have a secondary device, or wish to use one instead of the TV.

These problems arose because of a fundamental limitation of the TV: it has one shared physical view. However, this technological limitation is being overcome, with existing consumer TVs capable of multiplexing many separate views in what is often termed "multi-view" [3]. These allow users the capability to consume content independent of others in the room, whilst retaining the same shared focal point, utilizing technologies such as active-shutter glasses, lenticular displays etc. This paper investigates how we can design interfaces and interactions that support multi-view TV usage, enabling users to transition between both independent and shared activity, gain casual awareness of what is going on in other user's view, and to collaborate more effectively on shared activities.

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STUDY 1 - MULTI-USER MULTI-VIEW TV

The aim of our first study was to design, develop and evaluate a fully functional Android-based multi-view TV. Throughout this paper we chose one important limitation: that we would be investigating only the visual component of such a system, and not the audio. Enabling per-user audio whilst retaining the ability to hear and converse with others is an area of active research, with solutions ranging from bone-conductance headphones, to directional sound-beams (e.g. BoomRoom [6]) and it is reasonable to expect these systems being incorporated into future multi-view displays. The study had the following aims:

- To allow users to gain awareness of each others' activity through a simple set of behaviours by which they could transition between virtual views without compromising in terms of distraction, aspect ratio and utilized screen area;
- To show that a multi-view TV is superior to a single-view TV in a typical collaborative media browsing task;
- To determine the extent to which users were aware of each others' activity and how close this was to their optimum level of awareness.

In order to accomplish this, we designed and built a two-view (meaning two interactive virtual views), two-user (meaning the system supported two independent physical views made up of whatever we wish to render of the virtual views) multi-view system with the capability to allow two users to transition between collaborative and independent activity. An overview of this design can be seen in Figure 2.

We provided users with a simple set of touch gestures (enacted via a touchpad; see *Implementation*) to switch between the two available virtual views. These gestures were *transition*, which switched the user between the two available virtual views, at which point they were free to interact with the current view, and *peek*, whereby the user could switch to the view they were not currently interacting with for so long as they performed the gesture, at which point they would return to their current interactive view. Through these behaviours, we hypothesized that users would be able to adequately determine their awareness of each others' activity, transitioning between independent and collaborative states, and gaining awareness of what activity their partner was performing, if they felt the need.

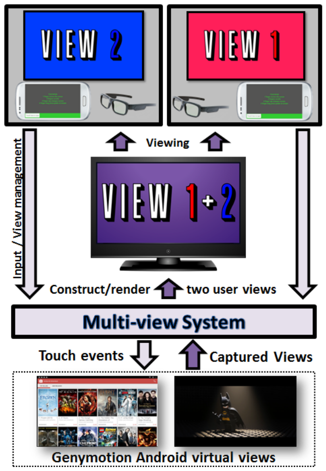

Figure 2. Overview of multi-view system in both studies. Here two users can have completely independent physical views (labeled View 1 and View 2) made up of however we wish to render our virtual Android views, with inputs routed appropriately.

Implementation of Multi-view Display

To provide users with a fully-functioning multi-view TV we realised that the typical approach of implementing software capable of allowing users to only perform a given task (e.g. implementing a multi-view photo browsing application) would not be representative of smart TV usage. Thus, we built a generalised, ecologically valid multi-view system that would give users capabilities above and beyond current smart TV capability, allowing them to interact with the kinds of applications that are commonly used. Given the adoption of Android into the smart TV area, we believed that building a system utilizing multiple emulated Android devices would best approximate this. As such, we used multiple instances of Genymotion[1], a high-performance x86 Android emulator, running Android 4.x.

To present users with entirely separate views, which could be of the same virtual Android device, or different devices, depending on the users current display settings, we utilized nVidia 3D Vision, an active-shutter IR transmitter for the PC, coupled with an nVidia graphics card performing stereoscopic rendering at 120Hz, 60Hz worth of "left" eye frames, and 60Hz worth of "right" eye frames. To provide users with independent views, we needed to be able to present only the "left" eye frames to one user, and the "right" eye frames to another. This was achieved using Youniversal active-shutter glasses[2] which had the capability to be set into a "2D" mode where only one of the left or right frames of the 3D image was allowed through both eyes. Our emulator screen-capture software then rendered a stereoscopic image, such that the left image constituted of whatever view we wished to provide one user, and the right image whatever view we wished to provide the other user. This gave users the ability to view separate Android emulators (hereafter virtual views), or transition to the same virtual view, all without affecting their partner's physical view. To minimize crosstalk, we utilized a 24" BenQ XL2411T Display which supported nVidia LightBoost, resulting in little to no perceptible ghosting between views; this was important as it meant that awareness could only be gained through our multi-view behaviours and mechanisms, not through inadequacies in the technology.

To interact with the Android virtual views, we used Samsung Galaxy S3 phones as touchpad devices, rendering coloured cursors which matched the colour of the user's touchpad on whichever view they were interacting with. Additionally, when occupying a view, a coloured eye would be rendered in the bottom right corner, to allow users to be aware of when they were both sharing the same view. These touchpads supported a simple set of gestures: dragging one finger moved the on-screen cursor, tapping one finger made a selection; dragging two fingers performed a scroll gesture; tapping four fingers caused a *transition* action, whilst pressing four fingers performed a *peek* action for so long as the fingers were present on the touchpad. Additionally, the physical back, home, and application switcher buttons on the S3 were mapped to the same functions in the emulator. Text input was provided via the S3's onscreen keyboard. These interaction events were sent to our software then routed to the appropriate Android virtual view via the Android Developer Bridge.

Experimental Design

For our collaborative task, we chose to employ the full breadth of capabilities of our multi-view system within the

[1] `http://www.genymotion.com/`

[2] `http://www.xpand.me/products/youniversal-3d-glasses/`

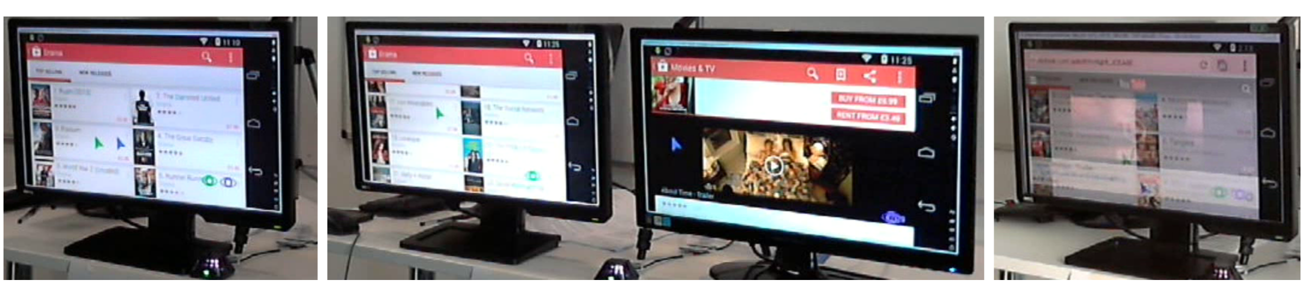

Figure 1. Left: Condition 1, single display with one virtual view. Middle: Condition 2, two displays, each with it's own virtual view. Right: Condition 3, multi-view display when viewed without active-shutter glasses. This supports two independent physical views (and thus two users), constituting of whichever Android virtual view each user wishes to interact with.

scope of common collaborative media browsing task. Users were instructed to browse a given set of categories of movies in the Google Play store application, with the task of selecting movies to watch together with mutual friends for the duration of each Condition. Three categories were selected for each Condition, with users instructed they could browse them however they saw fit. Additionally, users had the capability to watch trailers (with the instruction to moderate trailer viewing time) and use a selection of other applications if they so wished, namely the Chrome web browser and the IMDB app. As our platform was running Android, the applications they were using were the standard ones with no modifications, ensuring ecological validity.

The study design incorporated three Conditions: *(1) Single display* with one LCD display and one shared virtual Android view, as a comparative baseline for a standard smart TV; *(2) Two displays* with two LCD displays with a virtual Android view on each, allowing us to measure the default level of awareness of each others activity as users could transition between views by gaze; *(3) Multi-view display* with a single LCD display providing two independent physical views, each displaying either of two virtual Android views depending on the users usage of the system (see Figure 1). Users were tested for 15 minutes per Condition in a within-subjects design, and there were 9 pairs, 18 users in all (mean age=23.6, SD=5.5, 16 male, 2 female) recruited from University mailing lists as pairs that knew each other (e.g., friends, family, etc.).

To determine the effects on users' abilities to collaborate effectively, we utilized post-condition questionnaires from previous collaborative studies [9, 8, 5] from [4], as well as workload (NASA TLX [2]) and usability (System Usability Scale (SUS) [1]). Additionally, users were asked to rank the Conditions in order of preference.

To establish the default / optimal level of awareness of each others' activity, for the *two displays* Condition we recorded and analysed video footage of each participant, coding timestamps regarding which display the participant was looking at, if any. These timestamps, along with logs of viewing in the multi-view display Condition, were parsed such that we could accurately compare the viewing behaviour across Conditions. Where applicable, Gini coefficients were calculated. These are a measure of inequality used for analysing viewing distribution in previous studies[10, 4]; 1 denotes maximum inequality i.e. $100-0$ or $0-100$, and 0 maximum equality i.e. a 50-50 distribution when dealing with two items. As our use of Gini coefficients typically involves two comparison points, for both studies in this paper we also used directed Gini coefficients where applicable, whereby we encode the direction of the inequality such that 100-0 would resolve to 1, whilst $0-100$ would resolve to -1 (meaning the Gini coefficient resolved to a measure of distance between two points).

Results

Where appropriate a repeated-measures ANOVA (GLM) or Friedman test with *post-hoc* Wilcoxons was performed, green indicates $p < 0.05$. We found significant differences between the Condition 1 (single display) and Conditions 2 (two displays) and 3 (multi-view display). Conditions 2 and 3 were superior in terms of capability to collaborate (e.g. WS-1, MO-1), ability to work independently (WS-2), and workload/usability (see Table 1). However there were no significant differences between Conditions 2 and 3, with Condition 2 typically having only moderately higher mean scores.

Question	Condition			Friedman Test	Wilcoxon *Post-hoc* ($p < 0.05$)
	1: Single Display	2: Two Displays	3: Multi-view Display		
WS-1: We were able to collaborate effectively	3.11 (1.81)	4.94(1.21)	5.00 (0.77)	$\chi^2(2) = 16.0, p < 0.01$	1-2, 1-3
WS-2: We were able to work independently to complete the task	1.94(1.47)	5.67(0.49)	5.33(0.49)	$\chi^2(2) = 31.5, p < 0.01$	1-2, 1-3
WS-3: It was easy to discuss the information we found	4.39 (1.65)	5.50 (0.62)	5.39 (0.78)	$\chi^2(2) = 7.61, p < 0.05$	None
WS-4: We were able to work together to complete the task	3.94 (1.70)	5.28 (1.07)	4.78 (1.44)	$\chi^2(2) = 7.4, p < 0.05$	1-2
WS-5: I was able to actively participate in completing the task	3.83 (1.425)	5.61 (0.50)	5.33 (0.77)	$\chi^2(2) = 21.4, p < 0.01$	1-2, 1-3
MO-1: How well did the system support collaboration?	2.56 (1.72)	4.72 (1.18)	4.78 (0.88)	$\chi^2(2) = 17.2, p < 0.01$	1-2, 1-3
WE-1: The system was helpful in completing the given task	3.11 (1.68)	5.06 (0.94)	5.06 (0.87)	$\chi^2(2) = 20.8, p < 0.01$	1-2, 1-3
WE-2: I was aware of what my partner was doing	5.39 (0.85)	5.00 (1.33)	4.67 (0.97)	$\chi^2(2) = 9.48, p < 0.01$	None
PE-1: My partner was aware of what I was doing	5.28(0.96)	5.06 (1.06)	4.56 (1.10)	$\chi^2(2) = 9.49, p < 0.01$	None
TLX: Overall Workload	38.50 (24.70)	19.40 (16.00)	22.20 (15.40)	$\chi^2(2) = 10.6, p < 0.01$	1-2, 1-3
SUS: System Usability Scale	58.10 (22.20)	83.30 (14.30)	78.90 (13.80)	$\chi^2(2) = 13.2, p < 0.01$	1-2, 1-3

Table 1. Questions derived from previous studies. WS: WebSurface[9], MO: Mobisurf[8], WE: WeSearch[5], PE: Permulin[3]. Questions were 7-point Likert scale (results range from 0-6, higher is better). TLX is from 0 (lowest) to 100 (highest), SUS is from 0 (worst) to 100 (best). Means with standard deviations are presented across Conditions. A Friedman test was conducted with *post hoc* Bonferroni corrected Wilcoxon tests.

Viewing and Interaction

Examining the viewing patterns and behaviours exhibited in Conditions 2 and 3, we find significant differences in terms of viewing behaviour (see Table 2 and Figure 3). This difference is visualized in Figure 3, where we can see that in Condition 2 ~50% of overall viewing and ~90% of viewing instances were accounted for in viewing instances which lasted under 10 seconds; in comparison, Condition 3 demonstrates that users relied on much longer views, showing a clear difference in behaviour.

	Condition		
	2	3	RM-Anova
Mean Duration of Views (secs)	3.39 (3.51)	40.64 (37.40)	$\chi^2(1) = 16.6, p < 0.01$
Gini: Interaction	0.839 (0.27)	0.641 (0.34)	$\chi^2(1) = 3.75, p = 0.053$
Gini: Viewing	0.394 (0.233)	0.447 (0.306)	$\chi^2(1) = 0.356, p = 0.55$

Table 2. Mean (SD) viewing and Interaction comparison between Conditions 2 and 3. Gini coefficients show equality regarding how likely users were to view or interact with either Android view, 1 is maximum inequality, 0 is maximum equality.

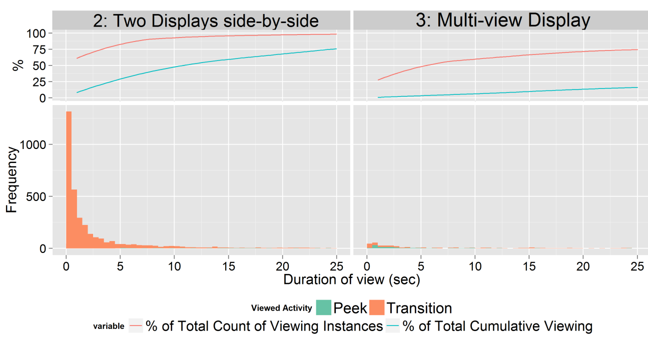

Figure 3. Individual viewing behaviour across participants. Bottom: Histogram (0.5 second bins) counting number of instances of viewing at a given duration. Top: Graph presenting percentage of overall cumulative viewing and percentage of overall number of viewing instances.

In terms of how this viewing was accomplished in our multi-view display, Table 3 demonstrates that our *transition* behaviour was utilized for the majority of this viewing, with the *peek* gesture accounting for only ~5% (~32 seconds) worth of viewing on average. Given that the peek gesture was intended to allow quick, casual glances at a partners activity, the lack of usage evidenced in Figure 3 suggests that this gesture, whilst utilized, was not sufficient for providing casual awareness.

	Viewing Mechanism		
	Transition	Peek	RM-Anova
Mean Total Viewing (SD)	566.8 (36.4)	32.9 (36.4)	$\chi^2(1) = 146, p < 0.01$
Mean Duration of Views (SD)	45.98 (36.3)	8.22 (18.3)	$\chi^2(1) = 13.5, p < 0.01$

Table 3. Mean (SD) viewing for Condition 3 (multi-view display) broken down by whether a transition or peek resulted in said view.

With respect to how likely users were to view or interact with (i.e. perform touchpad or textual actions on) either virtual view (see Table 2) there were no significant differences between Conditions 2 and 3. There was a bias toward equality with respect to interaction with the multi-view display, however this was likely due to the fact that once a user performed a transition in Condition 3, they were free to interact with the view they had transitioned to. In Condition 2, these transitions were typically managed by gaze, thus users would have to explicitly perform the transition gesture to then interact with this view. This suggests an interesting benefit of multi-view displays when coupled with touchpad remote controls: inputs can always be routed to the view the user is attending to.

Discussion

The results of this study demonstrated that a multi-view TV is superior to a single-view TV, which is not entirely surprising: as much as you can design an interface for multi-user use, the physical bottleneck of having to share the display inevitably negatively affects performance. The two-display and multi-view conditions could not be readily separated, with users gaining comparable awareness in each. The comparison between our multi-view display and the two physical displays did however demonstrate some marked differences not in how well users perceived their ability to collaborate or gain awareness of each others activity, but in how this awareness was accomplished. The two permanently accessible physical displays in Condition 2 were used to facilitate a casual and continual awareness of the activity of the other participant, through a multitude of shorter glances at each display. In contrast, the multi-view condition featured much longer views of each virtual view. Whilst we had attempted to facilitate the ability to gain casual awareness through the *peek* gesture, this difference in viewing behaviour and lack of usage with regards our peek gesture suggests that casual awareness is more readily accomplished by gaze, and not through system functionality.

STUDY 2: CASUAL AWARENESS IN MULTI-VIEW TV

The results of our first study raised a significant question. If perceived awareness and ability to collaborate was not significantly different between the two-display and multi-view conditions, but the way in which this awareness was accomplished was (with much shorter glances between displays), should we attempt to enable this more casual, continual gaze based awareness, and how?

Incorporating continual and casual awareness necessitates a compromise with respect to distraction due to other user's activity. Some aspect of the user's physical view must be used to provide this awareness. This goes against one of the primary aims of our initial study, which was to develop a set of behaviours that would allow for management of multiple views whilst not compromising the users current physical view in terms of distraction, aspect ratio and utilized screen. To study this, we designed a system that could answer the following questions:

- How much of their physical view are users willing to sacrifice to gain a casual awareness of other virtual views?

- Given the ability to transition between a casual awareness mode and a fullscreen mode, how would users appropriate such a system? Would they rely on only one mode, or use both, and if so to what degree would they use both modes?

We designed two additions to our previous multi-view TV system, applying the concept of the casual–focused continuum [7] to awareness. The first was to give users the ability to vary their engagement with others by directly controlling how much of their personal physical view was given up to awareness of what is happening in virtual views other than that which they are currently interacting with (see Figure 4). This was accomplished through the use of a slider on the touchpad (see Figure 5). At its extremes, it would devote the majority of the user's physical view to either to the virtual view the user was interacting with, or the other available virtual view; as the slider moves to the center of the touchpad, the user's physical view would begin to be split evenly between both virtual views.

Figure 4. Example of two users both in the dynamic split-screen mode, with different levels of engagement with each others activity. The user's currently interactive virtual view is always on the right of the physical view.

We anticipated that this mechanism could encompass a variety of behaviours, from selecting an appropriate ratio between the virtual views as a one-off, or repeatedly employing the slider to dynamically change the ratio between the virtual views as and when required, for example allowing users to be aware of a trailer their partner might be watching in the other virtual view. Through this, we hoped to establish if there were any norms with respect to how much of the physical view users were willing to give up for casual awareness. It is important to note that the aspect ratio of the content being viewed was preserved at all times, thus resulting in portions of the screen remaining unused, as can be seen in Figure 5.

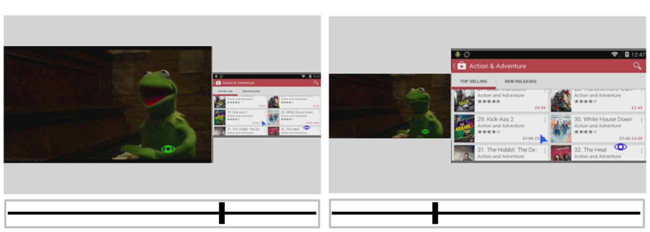

Figure 5. Example of the dynamic split-screen slider design. Here we see a user's physical view (shaded grey) being transformed Left: from a bias toward the currently non-interactive virtual view on the left; Right: to a new bias toward the interactive virtual view on the right.

The second addition was the ability to transition between this casual awareness mode and the fullscreen / fully-focused awareness mode that was the multi-view display in the previous study. As such, we incorporated a 3-finger tap gesture that would allow users to switch between the casual awareness mode, utilizing whatever screen ratio it was previously set at, and the fullscreen awareness mode. In both modes, the *transition* and *peek* behaviours functioned as before; in casual awareness mode, these actions resulted in the two virtual views swapping positions for that user.

Implementation

The implementation was the same as the first study, aside from the two additional interactions. Transitions between modes, use of the slider and transitions between views were all animated, with changes to the slider affecting the rendering in real-time. Users could interact with only one virtual view at a time; this interactive view was always to the right of the user's screen, and signified with a grey border.

Experimental Design

For this study, we had three Conditions. They were *(1) Multi-view display* which was the fullscreen multi-view display from the previous study; *(2) Dynamic Split-Screen Multi-view* which was a display that provided only the casual awareness mode; and *(3) Selective Multi-view* which provided users with the ability to switch between the modes from Conditions 1 and 2 using a 3-finger tap. As the aims of this study were primarily investigating how users would appropriate a system which supported both casual and fullscreen awareness behaviours, we chose not to counter-balance all Conditions. Instead, we counter-balanced with respect to Conditions 1 and 2, before moving on to Condition 3. This was done so that users received significant training with respect to using the fullscreen and casual awareness systems before using the dual-mode system in Condition 3. The same task design and post-Condition questionnaires were utilized as from the previous study, with 7 pairs of participants, 14 users in all (mean age=26.4, SD=3.3, 14 male) that again knew each other (friends, family etc.), recruited from University mailing lists.

Results

In terms of our questionnaire analysis from the previous study, we found that whilst the fullscreen Condition was often rated the poorest in terms of ability to collaborate, awareness, and distraction there were no significant differences between Conditions. Additionally, there were no significant differences with respect to workload or system usability. With respect to the proportion of viewing and interaction between the virtual views, there were no significant differences (see Table 4).

Casual vs. Fullscreen Awareness

Figure 6 details how the usage of our selective multi-view system compared to our comparative baselines. Here we see a surprisingly even split between behaviour usage in our selective multi-view system. Every capability, aside from the peek gesture, was utilized to a similar degree. Significantly, the most utilized function was our gesture for switching between

	Condition			RM-Anova
	1	2	3	
Interaction	0.73 (0.29)	0.65 (0.29)	0.75 (0.35)	$\chi^2(2) = 1.39, p = 0.5$
Viewing	0.47 (0.25)	0.57 (0.29)	0.55 (0.32)	$\chi^2(1) = 1.39, p = 0.5$

Table 4. Mean (SD) Gini coefficients for viewing and interaction. Gini coefficients show how likely users were to view or interact with virtual view. 1 is maximum inequality, 0 is maximum equality.

fullscreen and dynamic modes. Transitions between virtual views occurred in both modes, however somewhat diminished in the dynamic mode, supplanted by use of the slider for enacting changes in screen ratio. Indeed users appeared to split their viewing between the Dynamic and Fullscreen modes relatively evenly, as evidenced in Table 5.

	Viewing Mechanism		RM-Anova
	Dynamic Mode	Fullscreen Mode	
Mean Total Viewing (SD)	206.0 (212.0)	274.0 (212.0)	$\chi^2(1) = 2.23, p = 0.136$
Mean Duration of Views (SD)	26.6 (33.3)	30.5 (34.2)	$\chi^2(1) = 0.291, p = 0.589$

Table 5. Viewing for Selective Multi-view display, broken down by whether the display was in Dynamic or Fullscreen mode.

DISCUSSION

Our results indicate some interesting behaviours regarding how much of the display users were willing to allocate to awareness of others' activity. Users of the selective multi-view display dynamically varied awareness of their partners activity, the majority of the time dedicating between 7% and 43% of the display to this, but occasionally dedicating the majority of the display to awareness, whilst either retaining the ability to interact (the peak at 67%), or forefeiting interaction entirely by making the interactive view essentially non-visible (95%). We suggest that this approach could be used to determine empirically how much of a given display should be used for casual awareness (likely varying based on the physical properties of the display). However, given the dynamic usage exhibited it would be worthwhile to expose this functionality to users, if not in a continuous form then perhaps a discrete slider moving through derived ratios. With respect to how users appropriated our selective multi-view system, our management behaviours were utilized in both casual and fullscreen / focused modes, with some users reporting that, in the fullscreen mode, having the ability to transition between views was conveniently like having a "previous channel" button.

GENERAL DISCUSSION AND CONCLUSIONS

Through our two studies we have demonstrated a viable design for a multi-user, multi-view TV display. Our initial multi-view display was significantly better than the single shared display in terms of the ability to collaborate and operate independently, demonstrating a set of behaviours which allowed users to effectively share usage of the TV display whilst minimizing the impact on each others' physical view and capability to interact effectively. However, a viewing comparison between our multi-view display and a default / ideal awareness display using two screens indicated significant differences in terms of how this awareness was accomplished, with much shorter casual glances occurring in the ideal case. Given this, we iterated upon the design of our TV display, incorporating mechanisms to allow users to transition between casual and focused states, and dynamically determine their level of engagement when in a casual state. The usage of this "selective" multi-view system confirmed the importance of both modes, demonstrating that given the ability, users will transition between modes and vary their engagement with others' activity in both modes. In the fullscreen mode, engagement was varied through transition gestures, whilst in the casual awareness mode users dynamically varied their engagement through use of our view slider for controlling the amount of display given over to casual awareness.

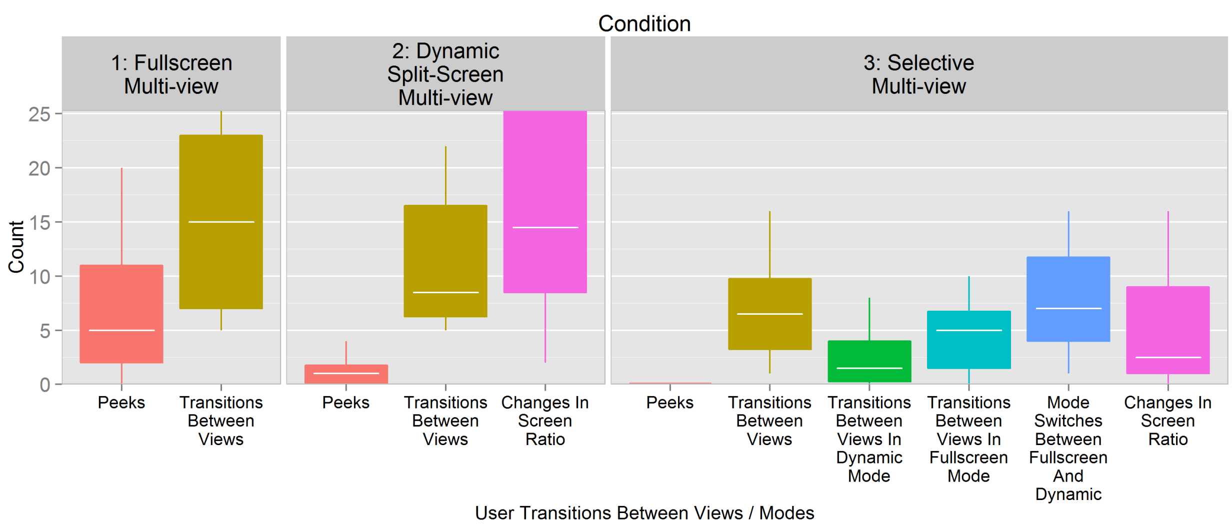

Figure 6. Boxplot of interquartile range of display management actions available to users: peeks (a non interactive look), transitions between views (moving between virtual views), changes in screen ratio (a slider manipulation), and mode switches between fullscreen and dynamic states.)

ACKNOWLEDGMENTS
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