Cross-Device Media: A Review of Second Screening and Multi-Device Television*

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Abstract

Television viewers interacting with second screens has become a common sight in the modern living room. Such activities are a mixture of related, semi-related, and non-related browsing of content. This growing trend is revolutionising the way that broadcasters think about their content. Through the envisioned connected home, driven by end-to-end IP connected networks, television content creators and app developers are now considering the design space for multi-device, interactive experiences. In this review paper, we consider the pre-digital beginnings of such scenarios, and progress to discuss how the introduction of mobile devices has affected the TV viewing experience. We discuss dual-screen usage over a variety of contexts in the connected home, with a focus on 'designed' dual-screen experiences such as companion applications. We conclude with reflections on the future of this area so that app developers, broadcasters, and academics may push further the space and improve future dual- and multi-screen experiences.

1 Introduction

Second screening is now commonplace in the modern living room. Recent reports, such as that by Accenture in 2015, estimate that 87% of TV viewing is accompanied by mobile device usage [50]. This statistic appears to show growth since Google's 2012 consumer study, which found 77% and that this was predominantly smartphones (49%) and laptops/PCs (34%). There is a large variety of usage (see Figure 1 examples), ranging from the wholly related: a user searching for an actor in a programme they are watching; to the totally unrelated, such as non-related social networking.

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Figure 1: Second screening takes many forms: one may engage with social media while watching a programme on a mobile device, as in a); read more in-depth information on a laptop, like in b); or download a dedicated application to get programme-related information and vote on live events, as in c).

Related browsing is generally driven by a user's want to know or understand something from a programme. And it is likely that unrelated second screen browsing is largely to do with the attentional requirements not be fulfilled by the TV programme. Research from 2012 by D'heer et al. [26] suggested that there was a great audience transformation underway – as many users are accumulating multiple devices, the 'traditional' TV experience is transforming. More recently, in 2014, Rooksby et al. [72], from observation of users using mobiles while watching television, have noted that device usage is a complex inter-weaved mixture of non-related, related, and semi-related content.

Related content viewing has led to broadcasters considering what, in the future IP connected living room, can be done to enhance UX (User Experience). Initial work has looked at how we may design bespoke, programme-specific second screen content to enhance television. This is most commonly referred to as companion content, which typically presents complementary information [60], related social media [9], and play-along games [20].

The field of second screens in the living room has exploded since the dawn of touch screen devices. However, no review currently consolidates the rich ethnographic, deployment-based, and lab studies of recent years. Therefore, in this review, we cover an extensive body of work done into designing multi-screen media contexts. We begin by discussing multi-display contexts in general – why the exist, and how these have motivated the multi-screen media landscape of today. We then examine the enabling technologies and adoption of such systems – discussing the state of the art in cross-device interactions with television content. Finally, we conclude by analysing where this diverse and emergent field is going, and the opportunities for future research it presents.

2 Multi-Display Contexts

Multi-monitor computing originates from a need to increase display space to view more information. Early multi-display systems were devised to concurrently view detailed pieces of information. Patents from the late 1970s suggest that engineers and scientists required more display space to view their data [11, 24], and therefore sought to increase their screen real estate by supplementing their displays with additional screens

by their side.

Over time, as computing capabilities have risen, and costs have fallen, multi-display contexts have become ubiquitous in information-rich contexts. As discussed by Grudin [36], such uses of display arrangement allow us to divide our screen real-estate with the physical bezels around the two screens separating them in the middle – allowing us to split our work across screens in a multitude of ways. Grudin's study found that additional monitors are normally used for secondary activities, and for peripheral awareness of content which is not the main focus of the user. For instance, one of Grudin's participants notes [36], that instead of clicking a mouse to cycle through windows to view a calendar, one can simply keep a calendar visible and instantly accessible in peripheral vision. Importantly, second monitors are not generally viewed as just 'additional space', but a partition to physically distribute work across and take advantage of our rich 3D spatial cognition capabilities – giving more added value than a larger screen would.

2.1 Peripheral and Ambient Displays

Interactions with some 'secondary monitor' to support more passive secondary tasks are commonplace. Much academic work focuses on the monitoring of tasks, for example through changes in ambient lighting (c.f. the work of Matthews et al. [53]), or through supplementary information on a small peripheral display (c.f. the InfoCanvas project [58]). Some early work by Wisneski et al. [87] also looked into how an environment may be enhanced by assimilating ambient, information-rich displays into our environment.

Now turning to peripheral displays in media contexts – 'second screening' [8, 29, 41], 'dual-screening' [15, 61], 'multi-screening' [83] and 'many-screening' [5] have become popular terms in the HCI for TV community. However, for the purpose of this review a significant point of discussion is *what constitutes a second screen?*. In general, when using the term 'second screen' we normally refer to a tablet computer or other type of mobile device such as a smartphone. However, we could argue that any display in which we present visual information alongside some kind of primary screen can be considered a secondary screen. Extensions of the screen [37, 82] through projecting outside of the TV, extending the entire screen to the wallpaper [40] are examples of how we are constantly trying to 'think outside the screen'. Further, if we are to take a step back and consider the rich continuum of a what can be considered a 'display', we could be referring to anything from a flat tablet screen, to a deformable UI [70], or perhaps an ambient Orb [53], a projection [44], or even a mixed reality physical entity in the room, such as a toy Dalek [1], which moves synchronised to on-screen Daleks during viewing [43].

Evidently, multi-display contexts have now extended from the more practical, productivity-focused endeavours, to media and arts to provide *experiences*. Utilising the physical partition between the digital worlds, and the increasing computing power and interaction capabilities of mobile devices, we may enhance realism, control, and foster a more tangible sense of space. However, though the bezels may have shrunk in these living room entertainment contexts, the distance between them has increased, creating two separate digital bubbles. Before considering this scenario we take a step back to consider multi-device computing, and the origins of multi-screen TV to evaluate the drivers behind such cross-device media contexts.

[1] Hostile alien machine-organisms from the BBC television science fiction series Doctor Who

2.2 Multi-Device Computing

Related to, but distinct from multi-screen environments, are multi-device systems, which involve computing experiences that span two or more devices. The focus of this article – cross-device media – is a clear manifestation of the latter. The ultimate goal of multi-device computing is in step with Weiser's 1991 vision of ubiquitous computing [86], wherein computers cease to act as single entities, but as one.

Multi-device eco-systems exist because there is no device which does everything optimally; each has its associated affordances. For instance, in a field study of multi-device workflows, Santosa and Wigdor [74] found that devices' form factors and capabilities are exploited in suitable tasks and that many of their study participants used their mobile to monitor emails, switching to their mail client on their personal computer when a call to action was initiated.

Such diverse usage introduces some interesting challenges around how we can create unified experiences with this multitude of devices. Dearman and Pierce's 2008 paper "It's on my other computer!" [25] makes evident the clear problems around multi-device computing, which manifest strongly around continuity between tasks on devices, the roles assigned to each device, and how we shared information between devices. More recently, since the explosion of capacitive touch-screen mobile devices, this has become an increasingly important domain of research, with Sheridan et al. [76] arguing that the smartphone is now indeed the ubiquitous input device. With the increase in computing power, and the dawn of cloud computing, many cross-device use cases are now being supported. Apple, for instance, offer Continuity [2] – a service which allows all major services on one's devices to be integrated, for example, to be notified and reply to a message on both mobile device and desktop.

Towards unifying cross-device experiences, much HCI research of late has focused on device-agnostic, multi-device applications. Pearson et al. express the importance of cross-device consistency in their work on the collaborative reading of documents [67]. Such design principals are reflected in many popular collaborative document applications, such as Google Docs[3], which allows users to share and edit documents in real time. Towards proving cross-device interfaces, much recent work has more focused on using web technologies to distribute UIs across multiple devices [88], and explore methods to afford the user(s) the possibility of sharing real-time dynamic media across multiple devices [48].

Though the emerging multi-device world has clearly transformed the way we interact with computers, it has also affected many other aspects of our lives. The way we watch television is a striking example of this. Although we have not always been fully-focused on our televisions in lieu of talking with loved ones or reading a book, the mobile device has overtaken the television as the main screen in our homes. We now examine the origins of this use case, towards understanding the origins, and the potential future of, multi-device television.

3 Origins of Multi-Screen TV

The second screen use case is a byproduct of our connected, mobile digital world. Our enthusiasm to interact with the digital while watching television is an increasingly prevalent behaviour that is transforming modern media. We are passive in the television experience as it requires little for us to engage with the content, and

[2]Apple's continuity: http://www.apple.com/uk/macos/continuity/
[3]Google Docs: https://www.google.co.uk/docs/about/

demands little from us. Compared to reading, for example, it requires little cognitive effort. To read we must investigate line by line; interpret the semantic information; conceptualise its meaning, and attach this to a mental audio-visual narrative. With television, there are often lulls in attention, and therefore we often freely interact with our mobile devices – searching related information, or engaging with information to keep ourselves stimulated.

This is not to say that the notion of multi-tasking while watching TV is a modern concept – it most certainly is not. Before digital ubiquity, we filled the gaps in attention with other side activities. Previous to this use case attention was divided in other ways, as noted by Schmitt et al. in 2003 [75], who monitored 50 individuals over 10 days with cameras. They found that television viewing was accompanied by eating, reading, or social interaction 46% of the time.

Before the digital age, many of us sought to support television through additional content. One could argue that pull-outs in magazines or annuals oriented around TV programmes were an early case of companion content to enrich the experience. Further, television and radio audiences have been connecting with broadcasters since the 1970's through letters, phone-ins, and even real-time interactive games such as The Golden Shot[4]. This increasing desire for two-way interaction between audience and broadcasters has manifested in the digital and is closer than ever to being realised.

3.1 Second Screening

Though there are many other cases where second screens complement another leisure activity (e.g., in the world of video games [18, 28]), TV is the primary focus of the HCI community, and many ethnographic studies document just how nuanced and far-reaching this use case is. This research has most commonly taken the form of in-situ studies of second screeners in their homes. Before the smartphone, in work such as that by Bernhaupt et al. [10] it was noted that users regularly interact with mobile devices as a foreground or background activity while watching television. Further, Tsekleves et al. [77] saw, in a study with 27 families, a strong desirability for the integration of secondary devices and services into interactive television services that are specialised to specific online activities such as social networks and email.

The proliferation of internet-equipped, interactive devices into our livingroom has, to some extent, filled the lulls in attention and our need to interact with content providers. A 2014 report from OFCOM [65], the UK's communications regulator, suggests that second screen interactions are skyrocketing universally across all demographics. There is vast usage of personal devices in the living room, and a rich set of literature around the HCI for TV community is trying to catch up with these trends and better understand this use case.

Work by Vanattenhoven and Geerts [81] further explores how people use a second screen in front of the television in the home. They worked with 12 households to record media usage and communication behaviour while watching TV or video. In general, they found that the majority of the reported second-screen uses were not related to the broadcast because viewers lost interest in the program – a pattern also noted more recently by Holz et al. [42] in their study which looked at app interactions when time synced to programmes in 7 households. Vanattenhoven and Geerts propose, to remedy such issues, that we may be able to use second screen applications to seize such moments to regain viewers' attention by providing additional social media, programme-related material, or further recommendations [81]. Courtois et al. [21] note a divergence of use in second screeners: those who focus exclusively on the television, and those who

[4]The Golden Shot: https://goo.gl/UTVOAJ

combine television with other media (e.g., laptop, tablet, or print media). They noted, in 2012, that whilst second screening is rife for tangential browsing, the potential of second screen apps is heavily under-utilised, findings also reported more recently (2015) by Holz et al [42].

D'heer et al. [26] looked at how we consume media on second screens in an everyday context through in-depth interviews with owners of multiple screen technologies. Further, Holz et al. [42] set out to understand this behaviour on a minute-by-minute level to gather a more thorough impression of users' motivations for device use while watching TV. By studying the usage of seven families, they were able to infer that the majority of second screen activities are unrelated to the programme at hand – only switching focus to the television at key moments.

Over the literature on second screening two prominent viewing patterns become apparent: second screen browsing which is *incidental* – i.e. they would be doing it regardless of the television's presence; and that which is a direct consequence of their television viewing, for example, someone searching for an actor they see in a programme – frequently termed *complementary* second screening. We now discuss the latter, focusing on applications created with the sole intention of extending the experience of second screeners with a vision to understand their availability, adoption, variety, and to discuss the empirical studies conducted towards improving cross-device interactions and experiences.

4 Dual-screen Television Applications

4.1 Commercially and Publicly Available

To provide insight into the current state of the art in publicly distributed applications we now describe some of the most prominent second screen applications for television programmes created by broadcasters and independent application developers. Initially, such applications began as small rollouts to test the feasibility of the infrastructure and the view receptability. For example, the BBC rolled out their Autumnwatch second screen application pilot. This trail, which was tested on around 400 members of the British public, blurred the lines between a research prototype companion app and a commercial deployment [2].

Since the Autumnwatch app, the BBC have experimented with many more applications. Examples include The Predictor [1] – a second screen application that allowed users to play along with The Apprentice and predict who would win. Further, they created an interactive play-along to accompany the Antiques Roadshow, in which the users had to guess – during the programme – how much particular artefacts were worth [5].

Other broadcasters have also explored companion applications to enhance the viewing experience. For example, Channel 4's Million Pound Drop Live application, in which users can play along with, and compare to, other contestants in the live programme [6], and a plethora of applications to create interactive, real-time experiences for major programmes Breaking Bad, and movies such as Avengers through AMC's StorySync [7].

Large media providers are also beginning to consider the use of additional content in their services. Amazon's X-ray [3], for example, features pre-loaded information within books and television programmes

[5] Antiques Roadshow Playalong App: http://goo.gl/RIIpFu
[6] Million Pound Drop:https://goo.gl/bXG7Sw
[7] StorySync: http://www.amc.com/story-sync

to add deeper insight into a particular moment. The material is bundled in with the programme and can be accessed offline through a second screen, or within the app itself.

4.1.1 Adoption of Second Screen Applications

The growth in companion applications over the past few years has been steady and met with mixed reception. Though general browsing on a second screen is ubiquitous, second screen applications are not. In 2014, OFCOM suggested that general uptake in companion applications is still relatively low – for example, one of the most popular programmes with a second screen app saw 547,500 downloads of its offering, which constitutes 5% of viewing figures. This statistic, however, doubled from 2013 and appears to be growing year on year – as of July 2016, there are over a million downloads on the Google Play store alone. In the 2014 OFCOM report, the most successful applications appear to be those which offer social aspects, for example, the 'TV Guide' app constitutes about 10% of UK viewers. As of 2014, Remote control apps for televisions tended to see relatively high, but non-majority uptake. Panasonic's Viera remote, for example, saw an uptake of about 25% of those who bought a Panasonic TV with such possible functionality.

Though there is clearly a demand, and some reasonable growth in the usage of companion applications there are a few major barriers to use which focus around second screening applications. One such barrier is the effort required to set up the dual-screen experience – often users must visit a specific link; or download an application, and rely on synchronisation technologies such as WiFi and audio watermarking. This setup cost can be likened to playing a board game – the enjoyment from the experience must outweigh the perceived setup cost, otherwise nobody will play.

4.2 Commercial and Prototype Companions: A Categorisation

Companion applications manifest in many forms to support our pre-existing behaviours. With this in mind, we suggest that we can categorise them by the behaviours that they support. We divide companion applications into the following broad areas: supporting tangential browsing; complementary social media; and as an extension of the remote control.

4.2.1 Supporting Tangential Browsing

There are numerous applications to support tangential browsing, which typically manifest to present passive information presentation to the user. Complementary content is provided at timed intervals, or explored through interactive information search, for example through tree visualisations [27]. This information is generally trivia related to a programme. In the simplest case this can be a series of slides with pictures and short blurbs to support the programme, for example, BBC's Autumnwatch deployment, which provided time-relevant information, typically simple graphics and text about the programme on a second screen. Such experiences can also be more interactive, for example, a companion app made for Channel 4's multi-platform campaign "Foxes Live: Wild in the City" [8]. The app, which ran alongside the programme provided the user with real-time information about wild foxes as they viewed them on live TV.

In addition to entertaining, these applications also have the potential to educate. Fallahkhair et al. [30] describe the potential for supporting language learning using a companion application. They describe an

[8] Foxes Live: Wild in the City: http://goo.gl/SfCNbY

approach that suggests presenting supplementary translations on a mobile device may aid in learning a language by clarifying terms in another language in English, noting that the individual content to assist understanding which does not distract those around them is a significant benefit. This point is later echoed by Vinayagamoorthy et al. [84], who note that secondary screens may be used for providing subtitles to the hard of hearing without affecting other viewers' experiences within the 'typical' living room TV experience.

Related to this, many such applications to embellish the second screen experience focus on providing additional information that allows a user to get a better gist of the programme and its characters as a whole. Such applications, in general, assist users in understanding complex concepts in a programme. Murray et al.'s [60] 'Story-Map', for instance, allows users to not get lost in long form television narratives. The app allowed for viewers to contextualise characters in relation to each other by making a map that described their ontology, allowing program viewers to provide some degree of back story, and a clearer understanding of the character relationships.

Dowell et al. [27] augmented an information-rich programme into an interactive companion application – in this case, they explore how information in an astronomy documentary can be summarised though interactive concept maps. In addition Eversman et al. [29] explored how second screen content can be introduced at key moments in a programme to link together Marvel's United Universe, creating a Transmedia [9] experience in which the affordances of each media are utilised.

4.2.2 Supporting Social Viewing

Television affords great social interaction (both colocated and remote). Though affected by genre (see [31] for more) it gives us a common talking point and brings together families in their living room. Therefore it is unsurprising that applications have been developed with an aim to support social viewing, as well as remote interactions through social media. The earliest indication of such interactions is work done by Microsoft – in 2004 Regan and Todd [68] explored how we may integrate online social functionality (instant messaging) into a media centre. Such early interactions, however, have been restricted to a single screen. Social second screening is now an everyday part of the television landscape – we follow hashtags along with living programmes and discuss events in real time (the extent of this 'live' effect can be seen in [49]). Social media such as Twitter is especially engrained in sports and live debate – to the extent where it can affect its outcome [52], and social media campaigns have also been shown to significantly improve brand awareness during major events such as the Superbowl [39].

More recently, many academics have then made the logical step to providing second screen interaction to television experiences. Much work around this was influenced by Geerts et al., who in 2008 looked at the implications of the genre on social TV platforms – essentially finding that news, soap, quiz and sport are genres during which our participants talk most while watching and are thus suitable for synchronous social interactive television systems.

In addition, in [32] Geerts et al. from a culmination of studies consider a series of heuristics by which designers of social TV systems may better design sociality. Second screening and time-shifted broadcast have become so popular that much work has explored how we can deal with spoilers – clearly, when we view programmes out of sync with their respective social media feeds there will be discontinuities. Basapur

[9] the notion of spreading a narrative across multiple platforms or devices – for example, a movie which is also a part of a comic book universe

et al. [9] while trailing their companion app, FANFEEDS (a companion content authoring app with a social element), noted several instances of spoilers – for example football scores being revealed in the social media feed by one participant before the other had seen the game. Issues with discontinuities such as this between screens have inspired people to look into automatically detecting spoilers in programmes (c.f. [13]), and even looking at detecting exactly what programme a user is referring to online [22].

Further to work by Basapur [8, 9], several academics have looked at how we may lower the burden of dealing with social media feeds and supported browsing over many apps by integrating them into a single application. For example, Hess et al. [38] consider a concept for unifying numerous TV-focused social media feeds into one manageable feed. Further to this, McGill et al. has looked at how we may better design for colocated shared experiences. In their work they have looked at how we can promote the sharing of personal content through screen mirroring [55, 56]. Their work focuses on extending the somewhat private world of the second screen to properly incorporate multiple viewers towards equal participation and improved awareness in multi-user multi-display contexts. This work utilises the sociability of TV, and extends the notion of families and/or friends gathering around their television sets to unwind – using television as a vehicle for conversation and 'real world' social interaction. Similarly, Anstead et al. [5] look at the effects of many-screen viewing on a companion application they developed to allow users to revisit highlights from the 2012 Olympics. They began with one shared tablet, and by gradually introducing new devices they were able to see the effect of introducing new media to the users. In general they found that the additional devices allow the users to be more personal in their second screen viewing, potentially unbalancing domestic tensions.

4.2.3 Extending the Remote Control

Irrespective of the technological developments over the past 20 years in the television remote still sits at the centre of television interaction. They are cumbersome, inconsistent, and bound by their physical limitations (Figure 2), as discussed in more detail in Bernhaupt et al.'s 2008 ethnographic study of living room trends [10]. We now explore work that has used a secondary screen to interact with the television; favouring the fluidity that customisation that soft interfaces afford. There have been numerous tablet applications released that allow for the control of a television with a tablet or smartphone. As previously mentioned, work in this area and the ubiquitous adoption of smart devices has culminated in manufacturers creating second screen applications which act as remotes/EPGs – the LG TV Remote; the Samsung Smart View; and the Sony TV Sideview to name a few. We now briefly touch on academic literature to gain insight into the work done, and how we may design for such control-based interfaces.

Work by Cruikshank et al. [23] explored what a customisable remote, such as a second screen PDA, can impart to the world of interactive television. They describe a solution that removes the interactive element from the television (or its remote), and transfers it to the a second screen (PDA). In doing this, the authors noted a "*dramatic improvement for effective interaction and navigation for iTV interfaces and services*". This delegation of interaction to a more suited device appears to not only allow improved interaction, but allows designers to save space on the main display to do what it does best: displaying.

To further interaction in such scenarios Bobeth et al. [12] studied methods for controlling a television app. They compared two alternatives to the remote control; air gestures, and a tablet computer interface. Results implied that mirroring the television on a secondary device and allowing the users to interact with this provided a more intuitive experience than the remote and the in-air gestures. Again, allowing interaction

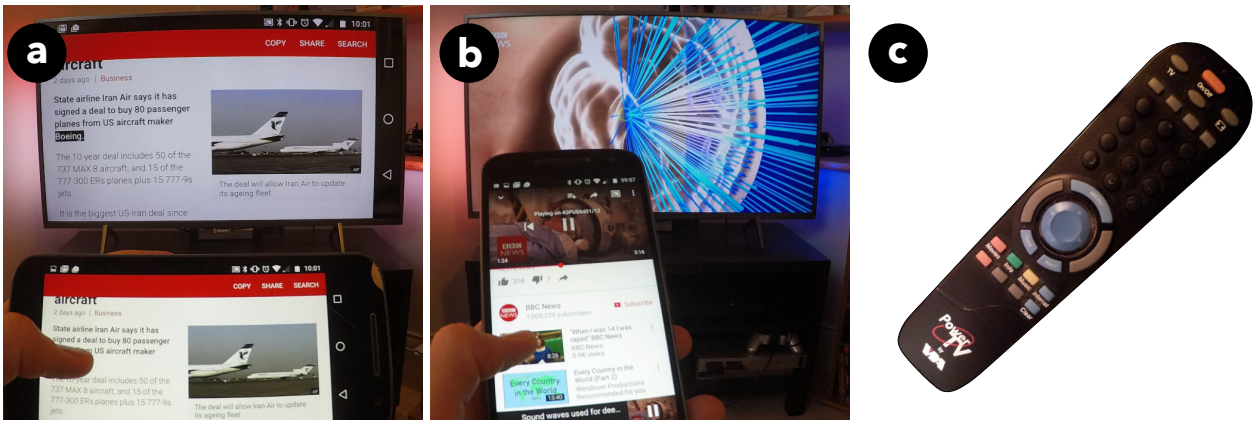

Figure 2: a) and b) depict two examples of modern second screen control of a television: precise control and cueing of video within a highly mutable backlit interface. In comparison, c); a television remote control, which is immutable and worn by years of use.

to be undertaken by the secondary device was shown to be significantly beneficial. Interestingly, their study also showed that older users, who are typically less familiar with tablet computers, adapted to the concept of controlling the television adapted quickly to the concept. EPGs are a cornerstone around which other second screen functionality can be added on – for example, [89] et al. explored the concept of designing a multi-screen EPG which linked other users in a similar style to a social network.

Though it is clear that secondary screen applications allow designers to leverage greater interaction benefits than remotes, the real impact is made when we consider the needs of those who require some degree of customisation for the device to control the television content. As the buttons on remotes are immutable they do not afford alteration of the interface. And, conversely, soft interfaces do. These benefits are made clear in the work of Barrett et al. [7, 43] – the Universal Control API allows barriers to be broken in terms of how the interaction method with the television can be adapted. As the API allows any configuration of interface to be developed, or for external sensor technologies to be used, the control style to adapted to the specific needs of an individual.

4.3 Attention Considerations for Cross-Device Scenarios

We now turn to consider attention considerations for those who watch television and engage with second screens simultaneously. Clearly, the consumption of multiple visual and auditory streams is likely to be tasking, and therefore much research has focused on understanding and remedying this. Media multitasking (the simultaneous use of multiple media streams) [78], has become the norm for many people, especially for television. Much research has investigated the effect that engaging with multiple information streams has on our retention of information. Patterson, for example, studied media multitaskers when revising for exams [66], finding that those who studied for exams while media multitasking were far more likely to score poorly in exams.

Generally, concurrent streams of information add extra mental effort to engage and generally results in poorer performance in comprehension tasks [4]. Moreover, the way we engage visually is changed. For instance, in 2011 Brasel and Gips [14] looked at how we divide our attention between a computer and a

television concurrently and found that people switch between media at an extreme rate, averaging more than 4 switches per minute, with little knowledge of their own switching behaviour.

In modern cross-device scenarios, these effects are likely exacerbated – we sit with the device in our laps, therefore meaning the television is in the peripheral of our vision as we watch television (and vice versa). This visual congruence between the visual foci leads to a great cognitive and visual disjunct – discussed more by Neate et al. [62, 64]. In addition, it is evident that users will have to engage with textual/visual content on the secondary device while monitoring the auditory feed of the television to engage with both screens – a task which is physiologically challenging [73].

The BBC note from their experience developing second screen applications that there is a continuum we must be aware of in terms of attention. While companion applications are designed to entertain, there is a limit to which they should distract from the initial programme for the dual-screen experience. In addition to the visual and auditory demands of the user, interactivity is also a vital factor to consider the users' requirements to engage with the application. As shown in Figure 3 it is clear that certain interactions, such as short text and images, are likely to require little concentration to engage with, but are likely also not stimulating in terms of interactivity. Interactions such as play-along games are likely to require great concentration to take in, both in terms of interaction cost and concentration. There is a tradeoff here – second screen content which falls into the upper right quarter of Figure 3 is likely to detract from the programme, whereas materials in the bottom left may not be enough stimulation.

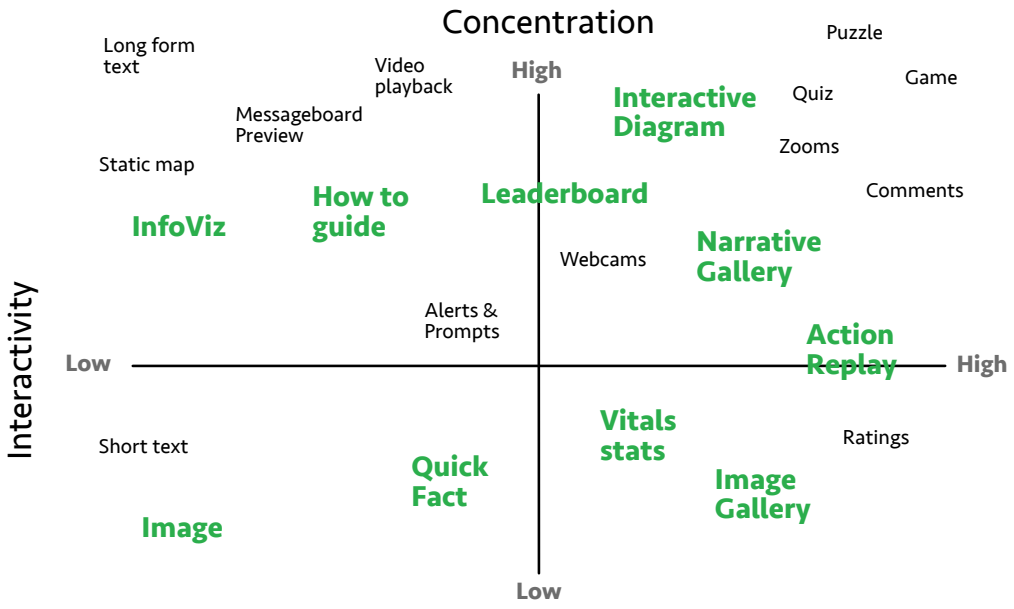

Figure 3: The BBC were interested experimented with various presentation formats of second screen interactions including diagrams, image galleries, etc. This figure, adapted from [45], describes their general conclusions – a map of interactivity and concentration in the second-screen. Green indicates the most common trends in second screen apps.

In addition to the rich ethnographic and deployment based research, there have been a variety of empirical studies around second screening towards understanding the fundamental attention constraints of the scenario. These have predominantly taken the form of lab studies. In 1996, before second screens were

ubiquitous in the living room Robertson et al. [69] explored the effect of a second screen in conjunction with a television. This early research showed that the distribution of information across the devices was essential – that the superior visual properties of the television should be used over the handheld device, such that the focus can remain on the mobile device's stronger interaction capabilities.

In the recent growth of the dual screen scenario, these findings have been extended by more empirical studies. For example, in 2012 Holmes et al. [41] looked at visual attention across screens via eye tracking. They found that when users interact with a synchronised second screen device they view the second screen content somewhere in the region of 30% of the time. Moreover, they found that this viewing was sustained even when the content was not being refreshed and that for each push of new content there were spikes in attention. Work by Brown et al. [15] further investigated this phenomenon. They looked at methods for eye-tracking across the screens and note the significant difficulties in doing so. In general, they provide insight into the attention switching and percentage of gaze such dual-screen scenarios attract. They detail a variety of complex and nuanced behaviours that such scenarios imply with regards to attention and interaction.

Further to the increased visual disparity between the two screens, Brown et al. [16] also reported that the users' attention often switches between the two devices due to a number of factors. The obvious of these being the content appearing on the tablet computer dragging attention toward it, or the user simply finishing attending to the companion content. However, it is evident that even when the content is not updating that certain events, on both devices, command attention. For example:

- **Scene switches** – for example an indoor scene changing to outdoor may catch the users attention and take it from the tablet to the TV. This phenomena is discussed in more detail by Valuch et al. [79].
- **Inactivity** – in both displays, inactivity, such as indoor scenes with talking heads and not much happening, tend to cause shifts in attention
- **Contextual cues** – Dialogue in the show (unintentionally) brining their attention towards the television, for example the presenter saying "*Woah! Look at that!*".

In addition to Brown et al. and Holmes et al.'s work on multi-screen eye tracking, Vatavu and Mancaş propose a visual attention tool kit [83]. In this toolkit they introduce a set of nine measures to characterise viewers' visual attention patterns for multi-screen TV. They propose quantitive and qualitative metrics by which to consider visual attention across screens. The work evidencing multi-screen interaction is a clear indicator that the dual-screen use case is thwart with issues relating to attention – complex auditory and video streams competing for attention are clearly going to have a major impact on users. Therefore, Neate et al. [61] have looked the direct effect of dual-screen complexity – the combined effect of the TV and the tablet content, and how they interact. They propose methods to alleviate attention overload, either by adapting the complexity of the tablet content around a set of heuristics dependent on the primary screen, or by allowing users to adapt the content themselves. Further, work such as that by Chorianopoulos et al. [19] has noted the importance of proper UI distribution for multi-screen contexts.

To better understand the effect of such multi screen scenarios lab studies such as that by Kallenbach et al. [46] are clear evidence of the great impact of extra information to a programme creates with regards to cognitive load. This is echoed in the work of Brumby et al. [17] who look at the effect of working with the television on. They found that when working with the television, we reduce our involvement with the television programme (and therefore lose the chance to relax). The work on dual-screen attention studies has generally implied that attention is sporadic and unpredictable. Moreover, in the second screen use case, not

knowing when new content is going to be introduced is a clear issue – users have to constantly check their secondary device, and 'keep their ear' on the TV (see [62] for a discussion of this area). Therefore, work by Neate et al. [63] looked at methods using additional notification-like stimuli to mediate attention between the foci. In general, they found that users wanted their attention to be mediated. Further, they looked at response times, finding that peripheral stimuli yielded faster attendance and that participants would defer their attention switch if they saw on-TV notifications.

4.3.1 Deployments

Deployments have been a popular method by which to explore the dual-screen use case. From developing companion systems and then deploying them, researchers have been able to gain deep insight into the use case. Basapur et al. [8], for instance, conducted a three-week trial of a companion system in 11 households. Their application provided time-relevant and semantically related information for a series of 10 popular shows over the study period. Their research showed that participants responded positively and that the prototype allowed the participants to better connect with their TV programmes. However, some participants noted that the 'pacing' of the auxiliary information required customisation by the user. Further, Basapur et al.'s proceeding work [9] explored a 12-week deployment of their companion application 'FANFEEDS'. For this, they developed a system that allowed for the authoring and consumption of time-synchronised, related content. In general, they found again that such applications enhanced the connection users reported with the programme, however, the participants also noted concerns around the inherent distraction a second screen experience creates from the television programme.

A large scale deployment was conducted by the BBC in which they trailed a companion application for the programme Autumnwatch. This was a synchronised web app that the BBC ran in browsers, allowing people to view a second screen in their own home. Overall, 400 people took part in this deployment, for which there was a synchronised, live, aspect, and a post-programme interactive menu to explore further. The application was received positively, with 92% of participants reporting enjoying the experience. In addition, there was a split between those who enjoyed using the application during the broadcast and those who enjoyed using it afterwards.

As with all systems, deployments are useful for gathering information about companion applications in a natural environment. However, it is evident that such analysis restricts researchers to basic usage data and post-event reflections from users. As Geerts et al. [33] discuss in their findings from discussions with viewers and producers, it is clear that the next step for studying companion applications through a deployment is to reduce barriers to entry such as downloads, installations and registrations. Finally, while data collected from mass and smaller deployments is invaluable, it can be contrasted and combined with information from systematic lab studies (previously discussed), which can gain deeper and more quantifiable insight.

4.4 Authorship, Sustainability and Artistic License

A significant question in the area of companion content is "where does the content come from?". The limitations and opportunities for creating sustainable applications are discussed by Messina et al. [57], whose work looks at developing an underlying architecture for efficient production of second screen applications,

for example, tools for authoring companion experiences. It is evident that the content can be created by the broadcaster or driven through quicker methods such as an algorithmic or a user-generative approach.

As discussed by Geerts et al. [33], the most common example of the generation of companion materials involves broadcasters creating second screen content to distribute to their audience. Examples of synchronised content are the aforementioned Autumnwatch experiment and the Britain's Got Talent companion app [10]. Problematically, such approaches are labour intensive and additional work is required to create the companion content. A potential solution is to develop algorithms that take information from the internet at specific points in a programme and render it in the application, attuned to the user's interests (see [54, 47]). Algorithmic implementations of content retrieval for second screens may use techniques such as data mining to infer appropriate content for users from the web, based on their viewing habits [59].

One could argue that the first approach, which is edited by a human and produced with the programme in mind, is likely to offer a more coherent experience with the artistic 'human-touch' that such a scenario can afford. One possible solution to this, proposed by Basapur et al. [9] outlines a human-driven companion content generating experience. Their system 'FANFEEDS' uses social networks to choose content from the web that is appropriate. They propose a points-based system in which users can become 'gurus' of generating content and therefore be more trusted to provide material that is both relevant and interesting.

Ultimately, it is up to the broadcasters to decide how companion content is created. On one hand, one can envision artistically created companion content, designed and edited in tandem with the television production to embellish the experience. Conversely, one could imagine a wholly algorithmic implementation which pulls content from the internet. This is highly context oriented. For example, programmes which a broadcasting corporation take a lot of pride in creating may be conducive to more orchestrated content, where as lower budget productions may have their companion content authored algorithmically. Crucially, the content – be it curated by humans or algorithms – should be engaging and complementary to the experience.

5 The Infrastructure of the Multi-screen Home

The notion of the connected home is making the vision of multi-device content more realisable. Given that recent reports are indicating that internet-enabled TVs are now the norm (according to a 2015 survey, internet-enabled TV penetration is $> 50\%$ [35]), that internet-enabled mobile devices are ubiquitous, and that most of us run these systems on a home network, the infrastructure is mostly in place. Therefore, recent work has looked into how we may integrate such additional infrastructure into normal practice for users with lightweight, extensions of their current usage.

There are several key considerations when devising cross-device infrastructure and systems for multi-screen experiences. First of all, there is the effort required for the user to pair the device with the television. This depends largely on whether one needs to download specialist apps, own certain hardware, or need some prior technical knowledge to initiate the multi-device experience. Secondly, there is the content's mutability to the device. Such factors are dictated by internet connection, the method of distribution and indeed the user's chosen device (i.e., screen size and form factor). Finally, there is latency – the extent to which content temporally synchronises across devices is vitally important for both for collocated devices

[10] Britain's Got Talent companion app – http://goo.gl/kCmcHv

[33] and remote shared viewing [34]. For instance, high synchrony is essentially for subtitles [71] and directors commentaries [43]. We now discuss these three factors in the context of existing technologies to provide cross-device media and remark on its potential future.

Cross network standards, such as the BBC's Universal Control API [7] are not yet a norm. However, the BBC's API allows for the control of set-top boxes and similar devices on a given network, and for all devices on a network to communicate. Such standards not only allow for interfacing for numerous Internet-of-Things (IoT) devices but also have strong implications for the design of custom interfaces. Recent work by from the BBC, by Vinayagamoorthy et al. [85], proposes an open communication standard between Internet-connected TVs and companion screens, over the home network. This work provides a standardised, frame-accurate, method to enable synchronisation between the TV and any personal device on the home network. Such endeavours, along with work such as that by Zorrilla et al. [90], which also looks at a method for synchronous cross-device experiences, may allow for seamless simultaneous multi-screen video experiences – such as alternate angles of live footage – with no perception of lag in the near future.

Another avenue of exploration in this area is audio watermarking (also known as audio fingerprinting), which has been used by a number of applications to synchronise, in time, the device and the television (e.g., in [42]). Audio watermarking overcomes the complications of client-server architecture by simply embedding imperceivable (over 20k) high-frequency audio cues in a piece of video material. These markers serve as triggers to cue content on the device, resulting in reasonable synchrony between screens. This method, however, has major shortcomings – most notable inconsistencies between devices, poor handling of user interactions and its proprietary nature [80]. It has therefore not been widely adopted. Parallel to this, however, much work has looked at standards for multi-stream, multi-device media synchronisation (see [80] for more detail).

Due to international standards, such as hbbTV (Hybrid Broadcast Broadband TV) [11], networked synchrony is improving vastly for collocated and remote shared viewing. This noted, technologies which allow for frame-accurate synchrony between a device and television are very much still at the research stage – for example the aforementioned the open communication standard proposed by BBC Research and Development [85]. However, as such technologies become more widely adopted by broadcasters and developers, it is likely that such networked experiences offer a strong future to cross-device experiences.

The future envisioned concept of media in the home is Object-Based Broadcasting (OBB) (see Figure 4). OBB is a responsive internet-driven approach to broadcasting in which separate elements of a programme are sent with associated metadata and assembled on the user's end to describe their assembly in accordance with the user's needs [6]. Such technologies would allow for the full customisation of content to the extent where each person has their own experience, curated to them.

6 Future Considerations and Conclusion

Though second screening is now ubiquitous, uptake and the development of, cross-device media is still in its infancy. In terms of adoption, such systems are still bound by several factors, some of which are in the research community's control. As we considered in the ethnographic research, second screening is a mixture of related and unrelated interactions. The related, which are of interest to us, are often done on the

[11] Hybrid Broadcast Broadband TV: https://www.hbbtv.org/

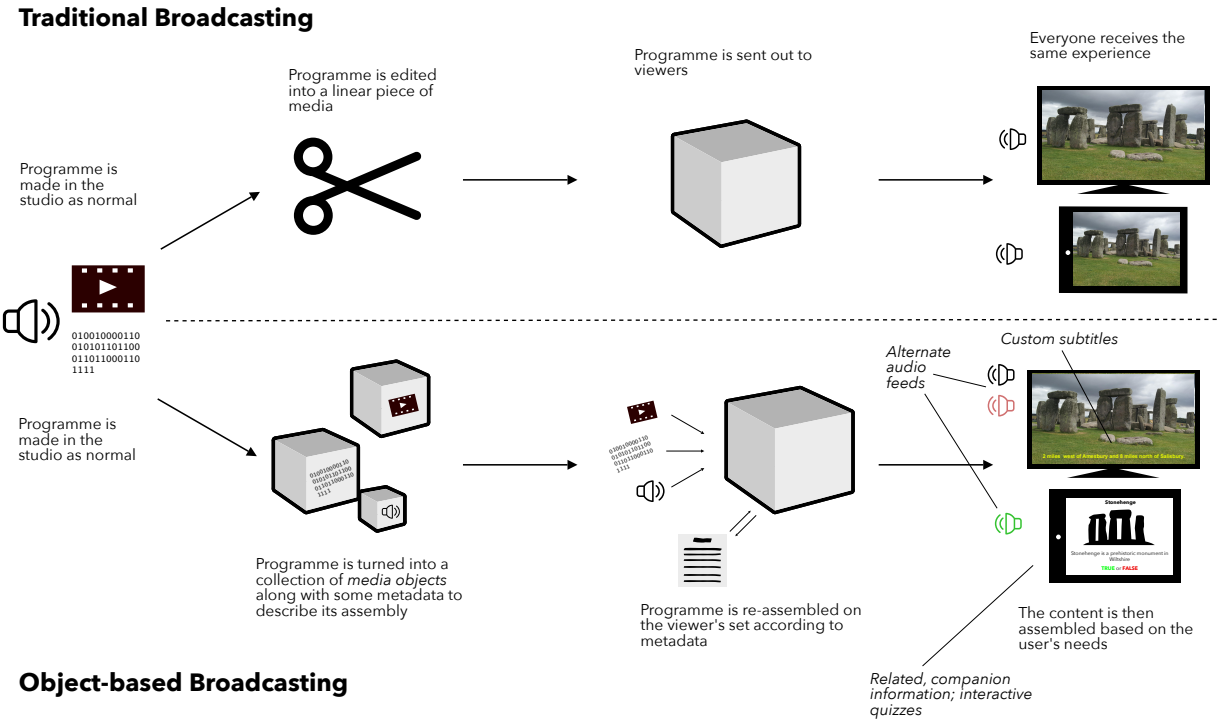

Figure 4: Object-based broadcasting paradigm, adapted from [51]. Providing content as separate objects has clear implications for second screening. Those with the capabilities to second screen, such as networked portable devices, may therefore be pushed content for their desired setup.

users' familiar applications – their web browsers; their social networks. We should consider how we can piggyback such technologies to provide better related content second screen experiences.

Considering factors more within the research community's control – it is evident that there is much to be done in terms of the technical infrastructure. As discussed in this review, there is a great number of methods by which multi-device experiences can be done, but no standard way to do so. The field – especially in HCI research – is disparate and largely uses proprietary or Wizard of Oz approaches to create inter-device experiences. To further innovation, the research community should aim to converge on a more standardised approach. Effective, open source standards, such as those proposed by BBC R&D are likely to be a strong convergence point, and it is up to the research community enable this.

On human factors in the multi-device use case – there is much to be considered in terms of how we design for the attention and the requirements of our users. Future work should consider each step of development the design of the scenario with the users in the loop – empirical studies should be run both in a lab setting and deployed longitudinally. We should build models of how users manage their interests and attention by

seeking insight from previous human factors research and develop models and interventions of our own. Finally, as with all research, it is down to those who develop the systems to heed it – strong feedback loops between industry, broadcasters, and researchers are therefore vital to the success of this field.

In this review, we have covered the state of the art in cross-device media – an exiting, fast growing, and potentially very rewarding area of endeavour. We initially explored the drivers behind the creation of inter-device apps – users freely interacting with devices. We explored why they do it, what they do and how we can extend their behaviours. By considering the current trends from industry and academia, we investigated from both an infrastructural; design; and research perspective, continuing on to consider the future of this rich field.

Cross-device media lays at the boundaries of Human-computer interaction, engineering, and media; and shares stakeholders in both industry and academia. This exciting new area of connected multi-screen homes should be approached from an artistic, an interaction design and an engineering perspective, without losing sight of the end user.

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