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The future of interactive information radiators for knowledge workers

How will knowledge workers consume ambient awareness information in the future?

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Abstract: Information Radiators (IRs) provide context-specific pieces of information in a semi-public place where a group of people can see it while working or passing-by. They can simplify information sharing "out-of-the-box", foster awareness and socialization, create serendipity and enhance collaboration. Recent sociotechnical developments such as the establishment of permanent hybrid work settings as well as advances in the area of Human Computer Interaction (HCI) such as the emergence of Augmented Reality (AR) and Virtual Reality (VR) are likely to impact how IRs are being used – or even challenge their usefulness. In this article we discuss those developments and their possible implications for the design and use of IRs in the context of knowledge work in the next decades. We argue that IRs will probably remain an important part of future office environments providing awareness, supporting serendipity and building a situated social place for matchmaking as well as informal communication. Using new display and interaction technologies (such as AR) they might even grow in importance by enabling fluid work scenarios.

Keywords: public displays; information radiator; knowledge worker; office of the future; augmented reality; awareness

1 Introduction

Knowledge workers are individuals whose primary role involves the acquisition, processing, analysis, and application of knowledge to solve complex problems (see for example [[1], p. 10] or[2,3]). Their primary assets are their expertise and skills. To perform their work, knowledge workers need access to various types of information, including:[4]

- ambient (or serendipitous) information, which helps them to stay informed as well as adapt to changes, but which they do not actively look for, because they simply do not know that it exists or that they might need it,
- awareness information, which is essential for achieving a common ground with their co-workers and also helps with decision-making, innovating, and continuous learning.

Information Radiators (IRs), ranging from non-digital large posters to digital, interactive large screens, facilitate access to these crucial types of information for knowledge workers.

In this paper, we explore the role of Interactive Information Radiators (IIRs) as ubiquitous, easily recognizable user interfaces that support knowledge workers within organizational settings. We focus on knowledge-intensive work as this domain is currently influenced not only by disruptive technological innovations regarding the way we interact with computing systems (advancements in HCI), but also by different other sociotechnical developments (trends). A notable trend is the growing adoption of hybrid work settings, which significantly affect interaction dynamics within organizations. In those cases knowledge workers often have not even physically met most of their colleagues. The virtualisation of our life and work (often conceptualised as "Metaverse") as well as new algorithmic support will (or already do) drastically facilitate knowledge workers' daily information-based routines. These developments are heralded as game changers regarding the way we work together – but how? And what are the implications of these developments for the design and use of future IIRs?

The next section starts with an overview of (I)IRs and their main functions for knowledge workers (Section 2). Afterwards we discuss current sociotechnical trends and their implications for supporting knowledge work with future IIRs (Section 3). Derived from this status quo we envision, how IIRs could possibly look like in future scenarios in

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the next decades (Section 4) and finally discuss the design decisions in the broader view of the trends presented before (Section 5).

2 Information radiators – state of the art

In this section we provide a brief overview of the state of the art in the domain of IRs (Sections 2.1 and 2.2) and summarize their main functions for knowledge workers (Section 2.3).

2.1 Origin and aims of the concept

The term "Information Radiator" has first been coined by Alistair Cockburn for frequently updated posters showing the current state in software development processes in a high traffic hallway.[5,6] The idea behind IRs is to represent relevant information in a way that is easily accessible to all team members or stakeholders, i.e. they can be understood at a glance. This promotes communication and understanding within the team and ensures everyone is on the same level of knowledge (common ground[7]). Early non-digital examples of IRs are Task Boards, Burn-Down-Charts or Kanban Boards traditionally printed as posters and hung up in semi-public places where all team members could see them while working on their artifacts.

The main goal of digital IRs in office environments is to provide pieces of information or in other words visual representations of information objects stored in the underlying data sources in a way that makes them consumable peripherally. In contrast to most other IT solutions which only show information after a certain user interaction (e.g. a query) IRs proactively distribute their "Info Particles" (IP) independently from any user. So, there is no direct need to interact with IRs – however the possibility to interact with IIRs might support its function. Regarding the input/output-modalities of the "Human-Centered Taxonomy of Interaction Modalities and Devices"[8] IIRs typically make use of printed text, images and videos for visualization of the displayed IPs and use 2D or 3D input in form of touch or (mid-air) gestures as ad-hoc input modality for further interaction.

2.2 Examples of (interactive) information radiators

IRs have a long history: from simple printed posters for agile teams, via interactive versions on large touch displays to complex situated sociotechnically integrated multi-user multi-device interaction spaces, augmenting physical working environments with peripherally recognizable digital content.

The use of large semi-public and public displays as IRs has been a subject of interest within the HCI and CSCW communities for a long time (e.g.[9]). There have been numerous studies of interactive installations in museums (e.g.[10]). Work on mixed reality solutions for collaboration has been extensively reviewed in Ens[11].

Most of the IRs in urban spaces are non-interactive information displays showing advertising and non-commercial information like news headlines, weather forecasts or sport results. Davies et al.[12] present an overview of this kind of digital signage solutions. They also discuss different observations relevant for the design of these solutions including the so-called "honey pot effect" or the "landing effect".

In addition to IRs in public spaces there are different solutions showing awareness information using other devices that are visible for multiple people in semi-public spaces, like artefacts emitting light in different colors.[13] Other examples of non-interactive information displays can be found in HCI and CSCW research, e.g. in the large body of work on ambient displays.[14] Hiroshii Ishii's work on artefact based approaches[15–17] adds on the basic ideas and contributes possibilities to interact with the tangible artefacts. One particular example of an ambient display that acts as IRs is the Aware Community Portal.[18] The setup consists of a projected display with an associated camera and server used to display items of relevance to researchers within a laboratory. The display shows live news and weather feeds, an hourly cartoon strip and a periodic clock update as well as a feed from a camera. Other examples can be found in the field of awareness support,[19] e.g. by Prinz et al.[20] with the TOWER environment showing workspace awareness information in 3D scenes on large screens.

In this domain we also have to mention media spaces[21] as "''electronic settings in which groups of people can work together, even if they do not reside in the same place or are not present at the same time.[22] Media spaces can help communicating awareness and enabling informal communication.

IIRs are less common than passive non-interactive large screens for advertisement, digital signage or awareness. One of the key challenges for those systems is making users "aware" of the offered interaction possibilities in order to entice for interaction. Vogel and Balakrishnan presented an early overview and thoughts about interaction with public ambient displays.[23] Some examples of research prototypes exploring the design space of IIRs over the past ten years are CommunityWall,[24] Plasma Poster Network,[25] Ambient

Surfaces,[26,27] XioScreen[28] and CommunityMirrors.[29–31] An example of a public deployment with long term evaluation can be found in the UBI-Hotspots project.[32] The different systems show both the potential of the underlying concept as well as the added value of interactivity, e.g. in the evaluation of the CommunityWall users considered at least 50 % of articles interesting enough to interact with them.[24] The evaluations also showed that people were willing to contribute to such a system by submitting content.

2.3 Semi-public displays as IIRs for knowledge workers

In the following subsections we summarize what (semi-)public displays as IIRs already contribute to support knowledge work. See for example[30] for further discussion of this issue. A similar feature analysis for digital signage applications that comes to quite similar results can be found in Khan and Jabeen.[33]

2.3.1 Information out-of-the-box, serendipity, awareness

One key feature of IIRs is that they provide proactive and opportunistic information supply for knowledge workers with pieces of information that are otherwise "hidden" in IT systems (see Figure 1). In Ott and Koch[30] the authors describe the following three things that can be taken "out-of-the-box" by IIRs:

1. Information objects out of the different "hidden" data silos where they are stored
2. Knowledge workers out of their restricted desktop-based working environment
3. Interconnections between the virtual world of (1) and the real world of (2) out of activity streams in Social Software.

Of course, this out-of-the-box effect cannot be applied for all kinds of data sources in equal manner. The approach can be especially helpful for information objects that are not searched deliberately, but profit a lot from being displayed and consumed peripherally, like e.g. activity streams and other awareness information. The overall concept of the out-of-the-box effect is also known as "serendipity",[34–36] which in general means finding information accidentally without having to look for it explicitly.

As amendments to classic desktops (not replacements!) the interfaces can help to create visibility about what is going on in the organization (awareness). Thereby, the additional interfaces can help to efficiently generate a better "common ground"[7] for successful collaboration. Awareness as "*an understanding of the activities of others, which provides a context for your own activities*"[37] is meanwhile widely spread in cooperation systems. The concept has been

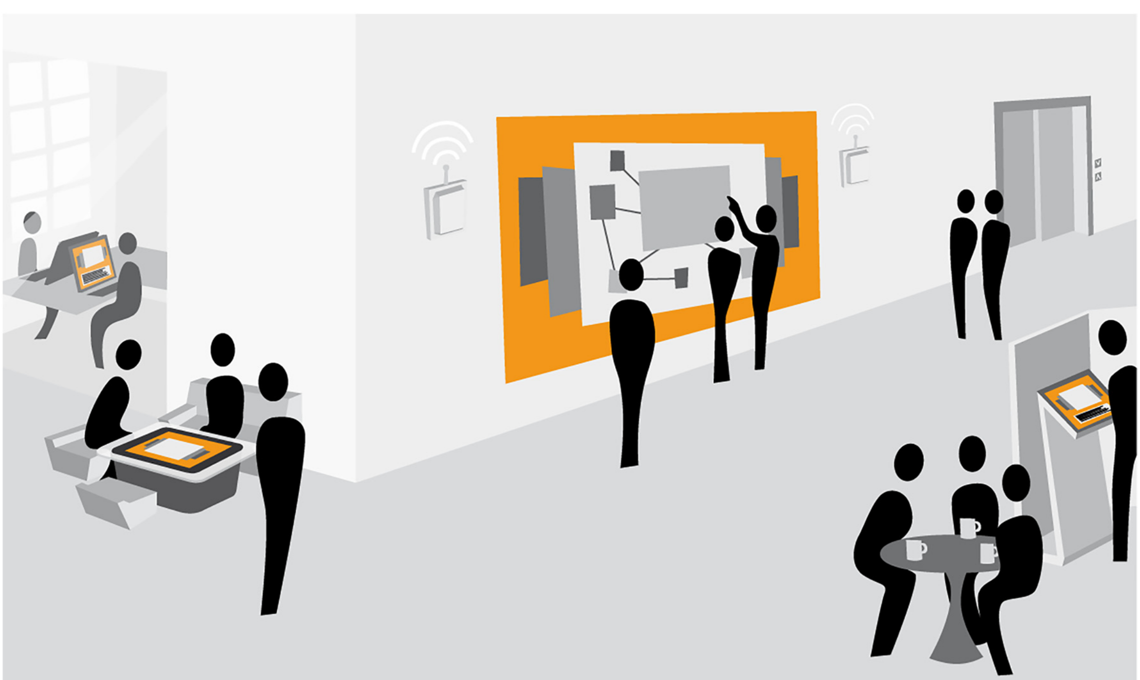

Figure 1: Semi-public IIRs in co-located office environment (from Ott and Koch[30]).

discussed for many decades in CSCW literature and can be seen as both enabler and facilitator for successful collaboration between knowledge workers.[38] The value of awareness comes from lowering coordination costs by enabling implicit coordination as well as from supporting different forms of intrinsic motivation.[39] This "appreciation through awareness" is especially important for knowledge work as the incitement of many people relies on their contribution being seen and recognized. By the extension of user interfaces beyond the desktop this potential can be extended to social situations allowing not only individuals to separately consume awareness information, but also groups of people to jointly watch and talk about activities of others. This in turn can help to foster "mutual knowledge"[40,41] through "consequential communication".

2.3.2 Situated social place for informal communication

IRs can be part of a complex "Ubiquitous Display Environment" and create a public spaces with various situated displays. The purpose of these displays is to provide relevant information to the people in their surroundings, directed to the regulars and visitors of the space.[42] The term "display" in this context is not restricted to typical flat wall mounted large screens or respective projections, but also includes various other form factors like horizontal (touch) tables (e.g.[43]), curved, tubular, spherical or flex displays (e.g.[44–47]) or (interactive) floors (e.g.[48]).

Envisioning a combination of multiple displays with different form factors in a semi-public collaboration space for knowledge workers in a modern office environments such an ubiquitous (multi-)display environment integrated into a corporate coffee corner could look like Figure 2 (adapted from the project described in Ott and Koch[49]).

Hybrid work settings inherently cause original interhuman communication to be artificially digitalized by using computer systems. However, knowledge sharing is a social process in which people share information in networks and communities. In this context public displays can go beyond physical barriers of single user desktops (cf. left side in Figure 2). The displays can be installed in different semi-public places, like beside the elevator, in the coffee corner or other social areas where people come together. The re-integration of information objects into their social surrounding enables people to directly talk about the discovered information without computer mediation.

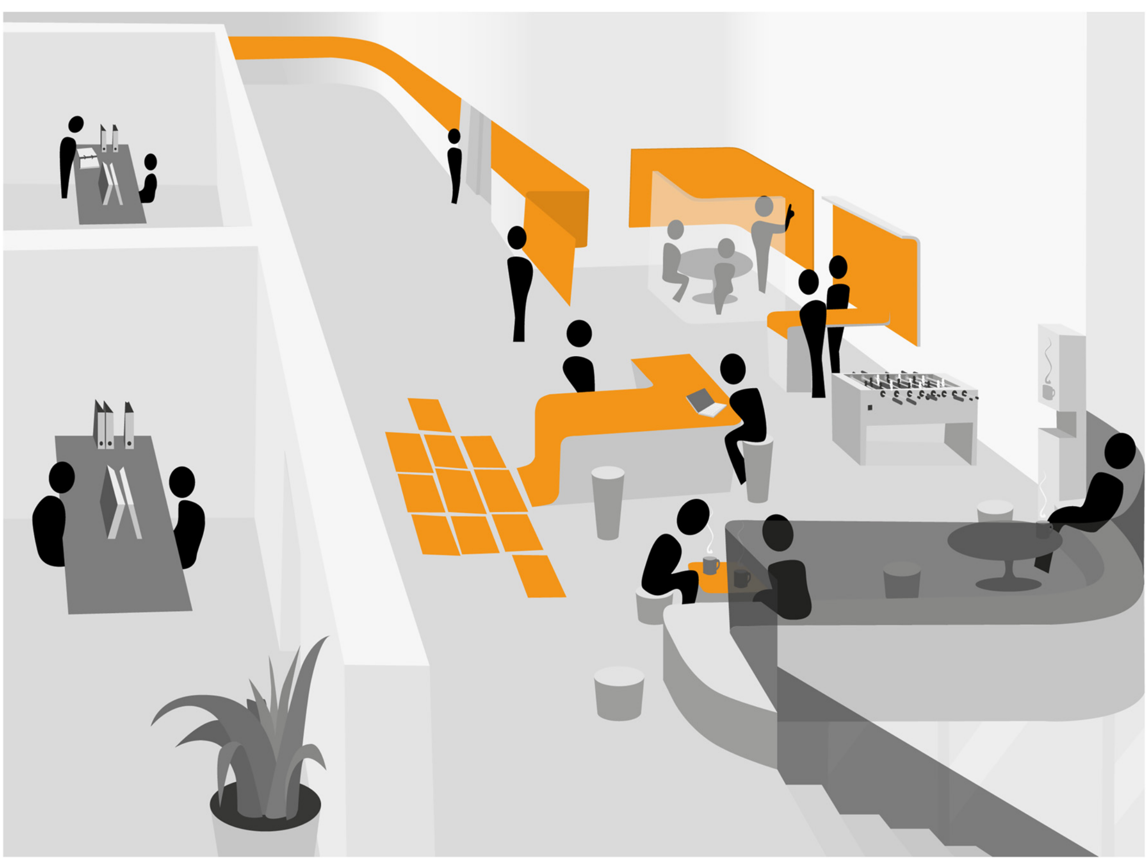

Figure 2: Natural open collaboration spaces (NOCS) as situated social place for knowledge workers (from Ott and Koch[30]).

From this perspective the following things are important for the sociotechnical integration of collaborative knowledge processes:[30]

1. Open physical spaces where people can come together and talk to each other willing to share their individual knowledge.
2. Semi-public user interfaces in these natural open collaboration spaces facilitating the access to relevant enterprise data sources.
3. Visualizations linking the virtual and the (real) physical world and allow “ice breaking” between people standing in front of the screens to motivate them for ad-hoc knowledge sharing.
4. New interaction paradigms that enable real “social” multi-user interactions for joint in-formation discovery and joyful collaborative browsing in information spaces.

Based on these assumptions IIRs can be seen not only as an additional user interface for knowledge workers, but rather as a socio-architectural situated space with different semi-public user interfaces in which both interaction with the displayed information as well as informal communication and interaction “around” the displayed information takes place. Exactly this situated social place is in most of the cases missing in hybrid interaction scenarios today.

In summary, IIRs can support (collaborative) knowledge work by providing awareness, simplifying serendipitous information discovery and building a situated social place for matchmaking and informal communication.

3 Current sociotechnical developments

The way users interact with technology has already changed seriously over the past decade. Based on continuously increasing usability of speech recognition and speech synthesis like within Amazon’s Alexa in combination with upcoming AI assistants like OpenAI’s ChatGPT interaction technology (IT) is meanwhile “calm” enough (referring to Mark Weiser’s vision from Weiser[50]) to disruptively change the way future knowledge workers will interact with IT systems during the next decade.

In this context different disruptive innovations and emerging technologies are currently discussed as “game changers” for IT systems, e.g. Artificial Intelligence (AI) – especially in the context of Large Language Models (LLM) and Natural Language Processing (NLP), AR and VR, as well as real Multimodal User Interfaces (MUI) as combination of voice, touch, gestures, eye tracking, wearables or even Brain-Computer Interfaces (BCIs) to create a more versatile and accessible ubiquitous user experiences. Together with future IT base technologies like Quantum Computing, Blockchains, 6G and the meanwhile omnipresent Internet of Things (IoT) these developments – especially those in the areas of HCI – will have a tremendous impact on the way knowledge workers collaborate.

In the following subsections we briefly discuss the sociotechnical implications of the most important developments for knowledge work and IIRs from our perspective.

3.1 Hybrid knowledge work in the metaverse

The recent rise of remote work, catalyzed by the pandemic, has led to the establishment of hybrid work settings, in which many knowledge workers physically meet their colleagues less frequently.[51] This change has introduced other challenges such as screen-based separation, where individuals experience a sense of detachment and may miss the awareness that comes with physical proximity.[52] The impact of teamwork that is primarily carried out virtually extends beyond the immediate task at hand. It reaches into the realm of interpersonal relationships, creating a void in the visibility that naturally arises from physical proximity.[53] This is particularly relevant for knowledge workers who rely on continuous collaboration and spontaneous exchange of ideas for innovation and problem-solving. In a traditional office setting, casual interactions in hallways or shared spaces contribute significantly to a collective understanding of team dynamics, fostering a sense of community and shared purpose. In the virtual realm, these organic moments are often lost, and as a result, the social fabric of a team can become strained.

These long-term dislocated hybrid interactions are meanwhile widespread in all knowledge intensive work settings. In this context the concept of the “Metaverse” has grabbed the attention of tech enthusiasts, researchers, and the public alike.[54] The Metaverse can be defined as collective virtual shared space, created by the convergence of the physical socio-architectural space, AR and VR including all physical and virtual entites of the real-physical as well as the digital-virtual “worlds”. For many years it represented only a vision of a connected digital future, meanwhile it blends more and more with our physical reality.[55]

The Metaverse is often hailed as a game-changer in how we experience virtual interactions and engagements. However, it is crucial to note that a fully developed Metaverse is still work in progress, and there are different opinions about what it exactly entails.[56] Big technology companies like Meta Platforms, Inc. (formerly Facebook) and Apple are taking different paths. Meta is diving into VR with products like Meta Quest Pro and the Horizon Workrooms platform, while Apple is focusing on AR, such as the Vision Pro glasses that blend digital experiences with the real world.[57]

The buzz around the Metaverse brings to mind previous virtual worlds like Second Life (SL), which was a big deal in the early 2000s.[58] At its peak, SL had over a million active users and was seen as a groundbreaking platform for social and business interactions. However, SL's popularity faded as it struggled to keep users interested and make money. Will the Metaverse face similar challenges, or is it fundamentally different from past virtual worlds like SL? As we explore this digital frontier, the Metaverse encourages us to think critically and imagine a future where virtual and real worlds seamlessly come together.

Interesting contributions on what scenarios in distributed collaborative work are working and why can be found in the CSCW literature e.g.[59] or.[60]

Regarding IIRs we can learn from existing deployment scenarios that especially socio-architectural spaces like the watercooler where knowledge workers "accidentally" come together for informal ad-hoc communication can help to generate sufficient awareness over the activities of others to facilitate cooperation in organizational settings. With new generations of knowledge workers who are used to work with colleagues that they may not even have met physically, there is a clear demand for digital-virtual equivalents of these real-physical socio-architectural spaces allowing situated interaction and mitigation of the digital-physical gap. This also implies that there is more need for presenting information about co-workers – while currently the IIRs mainly display content information.

3.2 Augmented and Virtual Reality, holograms

As technologies for accessing the Metaverse in AR and VR setting new wearable user interfaces, especially Head Mounted Displays (HMDs), have found their way from former use cases like gaming, aviation, engineering, or medicine to office settings with "normal" knowledge workers. In combination with new display technologies like projections of 3D holograms in real-physical socio-architectural spaces these innovation can be used to foster new co-located and dis-located interaction paradigms for future knowledge workers.

When SL as the first large VR environment emerged, there was a lot of talk about its usability for knowledge workers. For example[61] lists six reasons why VR is a game changer in office communication – e.g. by enabling novel knowledge-management practices for organizations via enriched data and information, immersive workflows, and integration with appropriate information systems as well as other emerging technologies. Different other solutions have been shown in the past e.g. for replacing physical monitors for more flexibility and screen space.[62] Ens et al. presented a broad literature analysis of collaboration through mixed reality.[11] In Biener et al.[63] several VR applications for knowledge workers (map navigation, window manager, code version control, presentation editor, medical imaging, information visualization) are described – mainly focusing on spatial interaction using HMDs that show several screens. The authors even did a comparative study with participants acting as knowledge workers in a VR environment for a full week, 8 h a day.[64] Among other results the authors of the study were confronted with different levels of simulator sickness, below-average usability ratings and two participants even dropped out on the first day using VR due to migraine, nausea and anxiety. So, the technology does not seem to be ready for full time usage today, but this may change. Other work on AR as an interface for awareness and orientation support can be found in Osmers and Prilla.[65]

AR for Ambient Displays is e.g. explored in Gruenefeld et al.[66] The authors present ChalkboARd, a prototype of an AR-enabled public display that seamlessly integrates into its environment. The field deployment of ChalkboARd provides evidence that AR for public displays needs to be interactive and adaptive to their surroundings, while taking privacy issues into account at the same time. In James et al.[67] AR headsets are used to seamlessly extend the collaboration space around a large wall displays. The study shows that with Wall + AR, participants use the physical space in front and around the wall extensively, and while this creates interaction overhead, it does not impact performance and improves the user experience. The usage of AR via HMDs in public space is also investigated in Mai and Hußmann.[68] The authors try to link the discussion to research on public displays (in particular the Audience Funnel, cf.[69]). They propose an adaption of the audience funnel concept on the usage of HMDs, discuss differences and present indications from a field study that the audience funnel concept might hold in the usage of HMDs.

For traditional display-based IIRs that are situated e.g. in a semi-public office space, like described above, a setting where similar IIRs completely reside in a VR that is accessed with HMDs would be basically pretty much the same as its physical equivalent – beside the loss of the real-physical interaction possibilities like e.g. informal (human-to-human) communication. The immersive and sensory VR-experience has several benefits, e.g. it allows remote knowledge workers in different locations to meet and collaborate in shared virtual spaces around virtual IIRs that can offer completely new visualizations and interaction possibilities as well as nearly natural immersive communication. Nevertheless, such a setting at least temporarily isolates users from the real world as well as the people around them (e.g. other knowledge workers at a physical office) and replaces the whole surrounding with a digital-virtual environment.

Because an IIR is not only a user interface, but rather a sociotechnical situated space we still see an situated architectural (real-physical) space, e.g. an IIR within a semi-public traditional office environment as "base use case" for future IIRs, that can be (1) used without additional AR, but also (2) enhanced by AR for local knowledge workers together with 3D holograms of (3) remote knowledge workers accessing the same space in VR.

3.3 Internet of Things and ubiquitous multi-device ecosystems

Meanwhile semi-public installations of (display-based) IIRs can already be seen not only as multi-user, but also multi-device environments, where knowledge workers can interact with a large display and other people, but simultaneously with different other devices they carry with them, fist and foremost smartphones, tablets, and notebooks. To allow interaction with public displays several authors have experimented with augmenting public displays on handheld devices.[70] A broader view is taken in DeWitt[71]. The author categorizes developments on the future of human-signage interaction in the following three categories: (1) Voice-Activated Interfaces (VUIs), (2) AR – co-opts people's smartphones or tablets into becoming part of the display interface for a short while, and (3) Facial recognition.

With the final rise of the IoT, a combination of different cameras and sensors with respective automation and control possibilities is meanwhile omni-present in office environments. Despite privacy and security concerns, the interoperability of these "things" also allows their usage for different purposes relevant to semi-public IIRs, e.g.

1. simple counting of knowledge workers in front of one display in order to generate different "user zones" on the displays with separated content,
2. user identification by face recognition allowing individual or group based personalization of displayed information objects,
3. or prediction of potential walking-paths of passers-by, which can be especially relevant for multi-display environments in which content follows the knowledge worker,

In DeWitt[71] a respective scenario for future digital signage is presented that is close to the one presented in the movie Minority Report: "*As people move through the lobby, the content management system would be communicating with them, sending them messages that are specifically relevant and interesting to them as individuals, and no two people would get exactly the same content at the same time. And they can interact with the content they're receiving right then and there, with minimal gestures, blinks, tooth clicks, or what have you. The entire space becomes a tailored content zone for each person in it*".[71]

3.4 Generative AI and AI-driven personalization

With the latest advancements in the field of Artificial Intelligence (AI) especially generative AI, like the GPT (Generative Pre-trained Transformer) series of models, has become very popular. Generative AI has already successfully been used for various applications, such as text completion, language translation, content generation, or chatbot development.[51]

Knowledge work comprises tasks that involve complex problem-solving, critical thinking, creativity as well as ethical considerations, empathy, and a deep understanding of social and cultural contexts. It often involves collaboration with colleagues, clients, and stakeholders, in which effective communication, negotiation, and teamwork are vital in such roles. Despite their potential, current AI models are still very limited in their ability to replicate these human interactions. Therefore, it has been argued that it is unlikely that generative AI will be able to perform these tasks so well, that it will be able to entirely replace knowledge workers anytime soon.[72–74]

It is more likely that generative AI will complement future knowledge workers by automating routine and repetitive tasks, aiding in data analysis, generating reports, and providing insights. This frees up human knowledge workers to focus on higher-value tasks that require creativity, judgment, and strategic thinking.[72,74] Hence, as generative AI drastically facilitates knowledge workers' daily information-based routines, social actors can focus more on "human-only skills" in the future.[75] Yet, this emergence of hybrid teams (of humans and AI collaborating) raises many further questions.[51] One specifically relevant question for the context of IIRs is how hybrid teams optimize the balance between AI-driven data processing and human-driven decision-making. Can future IIRs play a role in providing serendipitous information that may otherwise have been lost in teams where AI filters what information is relevant or not?

For future IIRs AI may not only provide highly personalized user experiences. Systems will also be able to adapt to individual preferences and behaviors, making interactions with technology more efficient and user-centric. In particular we see the following benefits of this development for the future design of IIRs:

1. Content creation and data augmentation: generative AI can be used to create similar and peripherally recognizable multimodal content for a specific domain of an IIR based on existing or currently displayed information objects, like summaries of long texts, charts, images, videos or even entire stories.
2. AI-driven identification of knowledge workers' needs: by analyzing (past) user behavior, cultural background and context-specific preferences, AI can customize the information displayed to ensure that it is most relevant to the current information demand of the respective knowledge worker, e.g. based on a ongoing project and also act as recommender system for similar content/users.
3. Group personalization: especially in simultaneous multi-user scenarios IIRs could benefit a lot from AI-based group personalization algorithms that are able to display synergetically valuable IPs for all knowledge workers around an IIR.
4. Natural Language Processing (NLP) and voice-based-interaction: together with new speech synthesis technologies generative AI has the potential to be one big next step in how knowledge workers can interact with computers, including not only human-like conversations with IT-systems, but also the recognizing and distinguishing between different knowledge workers in co-located multi-user scenarios.

Although the currently hyped buzzword "AI" suggests a kind of intelligence, LLMs or their applications like ChatGPT are still a piece of software or in other words nothing more than algorithms. Hence, we will use the more general term "algorithmic assistants" for such future applications in the rest of this paper – or just talk about software or systems that might include such algorithmic assistants.

One might argue that most of this functionality is already available today. However, there is still a lot of work needed to make it available for building IIR solutions upon it – from further developing algorithms for group recommendation to setting up infrastructures that allow the combination of the information needed to make it work.

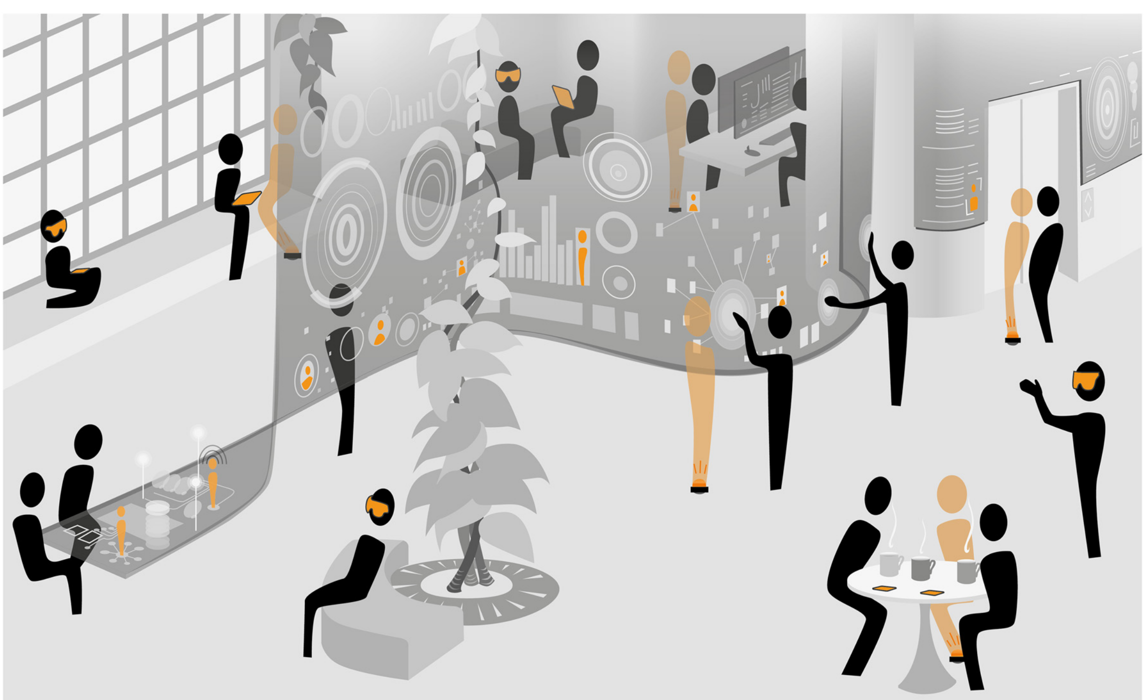

Figure 3: Local office in the future vision: Individual work with different interfaces and artefacts, collaboration with locally present or remote colleagues which are present via screen or as holograms, information radiators via AR, holograms or 'classical' screens/wallpapers (next to the elevator).

4 Information radiators for knowledge work in the future – a scenario

In the previous sections we discussed developments possibly influencing how knowledge work is done and supported in the future. Based on this discussion we now envision a scenario of how IIRs might look like in the future – see the text in the box and Figure 3.

With the scenario we are targeting a timeframe of 10–20 years in the future. This is mainly due to the time needed to make user interface developments "usable" in office environments. While the possibilities to generate personalized views partly already exist, the seamless integration of information sources in this area surely may need another ten years or more. Providing AR devices suitable for everyday and all day use will take much more than ten years.

The following scenario is based on two assumptions: First, there will still be knowledge workers (needing IIRs). Second, the knowledge workers will still spend some of their working time in office spaces. See Section 5.1 for a discussion of these assumptions in the context of the "Office of the Future" in general.

The used scenario approach helps us to cope with the uncertainty that comes with engaging with future developments and their implications. Unlike predictions or forecasts, scenarios are constructed narratives that combine predetermined events with crucial unknowns imaginatively.[76,77] Hence, we use the scenario to envision the future by incorporating uncertainty into narratives and making implicit assumptions about the future,[78] allowing for a deeper understanding of the future and its potential challenges and opportunities.

Alan develops new products for advanced personal information management in the company MyBrain. MyBrain employs 1.500 people working in 20 offices around the globe. The offices provide physical working spaces and the possibility to participate in advanced virtual co-working spaces.

The knowledge workers collaborate in different group settings via non-digital artefacts (paper, boards, …) as well as on different types of interactive surfaces in various form factors (handheld, desktop, large screen, tabletop) in the office, with colleagues from remote offices or working from home, including flexible display areas integrated into the architecture and furniture depending on the task at hand.

When working, Alan wears an advanced set of (see-through) AR glasses. In the background an algorithmic assistant observes what Alan is doing and determines what information might be useful for his current task or for changing this task to a more relevant one. A selection of this information is displayed in Alan's field of view (using the AR glasses).

When working concentrated alone or in a group (with co-located or remote colleagues) the AR glasses do not display any additional information.

When not in concentrated work, the algorithmic assistant will select information or people that might be interesting for the current work and display information about these info particles and their relation to the current situation. Alan can select an information particle and display more details in the AR display or directly on his pad.

When walking in the office information particles are presented that are related to what is happening around Alan. In addition to co-workers that are there physically, remote co-workers that are connected are dispayed. Again, Alan can select information particles and browse them in the AR display or on his pad.

The physical office has two semi-public situated social spaces equipped with IIRs, one beside the cafeteria in a coffee corner and one integrated into a hallway beside the elevator. Beside different interactive surfaces that are used for proactive information supply synchronized with the individual AR views the architectural spaces provide different "playful" interaction possibilities like e.g. table tennis or a kicker. When Alan is at the office he can access the IIR spaces physically. His colleagues working remotely and also having a break at the same time can access the spaces virtually (through their AR glasses). When doing so, they can be seen by Alan as avatars in the common augmented IIR space – either through his AR glasses or in form of 3D projections (holograms) in the physical space.

All knowledge workers currently (virtually of physically) present in the IIR space are identified based on sensor networks and camera tracking with face recognition. The software uses a group personalization algorithm to dynamically show joint relevant content from the projects of all present knowledge workers on the different large display areas as well as in 3D projections. Links between the different IPs as well as all people accessing the space are shown on the interactive surfaces. Further individual annotations, like the relation of the shown IPs to the own working context or the inter-person-connections to all other (even individually unknown) people present at the IIR space are displayed to Alan.

Simultaneous multi-user interaction with the shown information is possible by touch and air-gestures on/in front of interactive surfaces as well as via speech interaction with the algorithmic assistant of the space. The IIR space is equipped with dynamically adjusting directed microphones and speakers. Together with the individual AR interfaces this enables all participants of the IIR space to directly talk to each other individually or in groups allowing informal communication around the displayed information.

So far an attempt to summarize how future office work involving IIRs might look like. Lots of the design decisions in this scenario need further discussion – also of alternatives – which we will do in the following section.

5 Discussion

The envisioned scenario in Section 4 illustrates how IIRs for knowledge workers might look like in the future. We have sketched the scenario around five design issues: place of work, visualization, interaction, personalization, and social space.

As described in the scenario above, we assume knowledge work will still be done individually or in different group settings via non-digital artefacts as well as on different types of interactive surfaces in various form factors. Personal AR solutions, especially as see-through AR glasses as well as voice-based assistants will play a decisive role for knowledge work.

5.1 "Place" of work

The future of IRs is closely related to the topic of the "Office of the Future" in general. Most discussions in this field conclude, that there will be physical office spaces in the future. Perhaps smaller, with less commute time, with regular days of work from home.[79,80]

First technical concepts for the future office spaces can be tracked back as far as the i-land concepts or similar work at the MIT in the past century.[81,82] Newer concepts can be found in Knierim et al.[83] The need for IRs (awareness, common ground) is unquestioned. The current developments will change knowledge work practices, but there will be face-2-face work for the foreseeable future.

Future IIRs will play an important role to connect the different possibilities for the place of work. They might even provide the technology that is needed to make some (combinations of) places possible. For example, there is currently a discussion of bringing knowledge workers back to the office (after moving to remote work during the pandemic). One reason for the request is that remote collaboration is missing the benefits local offices offer regarding awareness and social place.

In our opinion future work will not be only office, only VR or only whatever, but it will be a flexible combination of all of these. People will work in.

- company-owned real office spaces
- co-working spaces (with employees from different companies)
- home office, beach office – collaborating with other using IT like video conferences, VR, …

Future IIR solutions have to support a mix of all these places of work. The different places of work pose different requirements to the IIR solutions. For example, co-working spaces have to take into account that there are people from different companies present in the space. Because of that IIRs should not publically show classified information or remote people from ones company – this information should be shown only to authorized individuals. On the other side, an IIR solution might more easily propose potentially interesting contacts across company boarders by showing knowledge workers similar interests or fields of work as "ice-breakers" for informal communication.

5.2 "Displays" and visualization

In future scenarios as envisioned in many books and movies information is frequently directly projected into the vision of people via the visual nerve which makes AR glasses obsolete. The vision goes beyond projecting the information onto the retina but directly triggers the connection from eye to brain or the visual center of the brain (with whatever technology still to be invented). In these visions, IRs like public displays often disappear as separate devices and are realized as part of the AR. A quite prominent example for this idea is "Hologrammatica" by Tom Hillenbrand.[84]

However, this is still "communication through the senses" and not directly into the brain. Hence, we assume that in the future communication from machine to man will be through the senses (visual, auditive, …) and not directly into the brain. Developments in the latter might lead to completely different solutions.

Assuming AR and/or VR will become ubiquitous over the next years, (i.e., people wearing such devices all the time – either by enhancing vision in some way or by installing "Holonets" as described in Hologrammatica) this opens up interesting ways to implement future user interfaces for knowledge workers. For the field of public displays envisioning such a scenario opens up the questions if there remains an application for "traditional" public touch displays, or if the type of interfaces will become extinct.

We believe there still will be different types of large "displays" in future offices beside AR glasses as additional highly relevant "display area". On the one hand, there will be large interactive surfaces in different form factors for traditional group tasks in physical meeting settings in which remote co-workers can participate, e.g. by AR. One the other hand, there will be a lot of "ubiquitous display areas" that are completely integrated into the architecture an can partly be accessed physically, e.g. in situated IIR-spaces in office environments, or virtually through individual AR/VR technology. First developments in this direction already can be seen for virtual meeting solutions,[85,86] but are still handicaped by the fact that today people use AR just for a single task and remove the glasses afterwards.

Looking at current AR/VR solutions, the important peripheral vision is much less present than in real live. This minimizes a lot of the potential of IIRs. In a current study, in which participants were working in VR for an entire week "for five days, 8 h each day" it was shown, that with current technology a full immersive office environment is not possible.[64] Will this change in the future? It seems realistic that knowledge work will increasingly (and for longer periods of time) happen in VR. However, research, as illustrated above, indicates that people still want to work with classical media, and still want to meet co-workers in real life (if possible).

5.3 Interaction

In the past decade, touchscreens have become more ubiquitous as physical user interfaces than ever envisioned by the best-known pioneer of "Ubiquitous Computing" Mark Weiser.[50] Yet, as shared devices in semi-public places touchscreens come with some drawbacks. They quickly get dirty, there is a (mild) risk of spreading illness or infection, and if touched too much they might even stop working correctly.[87]

Based on technological innovations in the field of HCI like voice-activated interfaces, eye-gaze tracking, holograms, gesture controls, or new wearables for AR and VR the question is, as e.g. Derek DeWitt recently wrote, will people in 50 years look back and say, "Wow, did they really used to actually touch screens with their fingers?"[71]

So, it is questionable, whether (physical) touch interaction has a future as today's mostly used (2D or 3D) "Input Modality"[8] for IIRs. We assume that in this regard, interaction with digital surfaces or AR projections (and the respective IT systems) will take place by (direct) touch, (mid-air) gestures, voice and brain-computer-interfaces as well as partly still device-mediated (e.g. classic keyboard/mouse, digital pen). IIRs will use the full range of interaction possibilities from voice interaction over gestures to computer brain interfaces (see for example[33] for a discussion of different current and future interaction methods for digital signage).

Regarding AR based interaction with IIRs we assume that – beside potentially usable bionic interfaces in the future – selections and further input actions will mainly be done by mid-air gestures in the direct view field by the knowledge worker wearing the AR glasses as well as through speech input to an algorithmic assistant. Output on the other hand might also include haptic feedback of actions performed by the system and interactions by the user, e.g. when "touching" objects in virtual projections.

5.4 Personalization and algorithmic assistance

A further major change regarding the display side of IIRs might be in the use of omni-present identification and personalization technologies with camara-based profiling or other approaches. We assume that through AR every user will get individualized views on information. However, it will be important to also show the presence of other users – not only for appreciation and motivation. Regarding that, current physical approaches lack sufficient "intelligence" based on behavioral monitoring and generation of multiuser situation models as well as respective group personalization algorithms that proactively bring knowledge workers together based on the projects (information) they are currently working on independently from each other. We see a lot of potential for effective knowledge work in this "Guided Matchmaking" process, but the required system guidance first of all needs better knowledge about what is happening in front of the displays as well as about the background of present knowledge workers. Regarding that, camera-based profiling, neural implants or simply personalized AR glasses have the potential to identify (potential) users and offer group personalization in equal manner for locally present and remote knowledge workers (or rather their avatars).

When looking into visions of future software support in knowledge work (e.g. as in Fischer[88]), there is always an "assistant" present. In the Human-Assistant team the assistant part will take different roles.[88] refers to Belbin's nine team roles.[89] In this model an assistant is very well suited to be assigned the role of "Resource Investigator", "Implementer" or "Completer Finisher". Additionally, Fischer mentions that there are also less task-oriented roles that are more important for the dynamics of the team in fields like motivation that might be taken by an algorithmic assistant. Regarding IIRs we assume that algorithmic assistants will especially play a role as alternative input modality for interaction with the displayed content in form of "show me … ". Voiced based interaction would enable algorithmic assistants to also answer/talk back to knowledge workers, but even with very locally directed speech output this could highly interfere with human (multi-user) conversations in front of the IIRs and thus is more relevant for individual concentrated work settings than for user interfaces in semi-public spaces like IIRs.

5.5 Situated social augmented space

We envisioned that physical offices will have several semi-public architectural spaces equipped with large interactive display technology and situated around "social places" like open (coffee) kitchen areas or indoor play courts. This allows the knowledge workers to come together and have informal conversations. Physical interactive surfaces in this areas will be more integrated into the architecture and furniture and allow personalized ad-hoc access to individually relevant information based on the person standing in front of a surface as well as proactive information supply as IIRs based on the group personalization algorithms described above.

Greuter et al.[90] state that "VR's immersive nature engages only the HMD wearer and excludes everyone else in the public space, and there is little design knowledge of how to engage those not wearing an HMD". To address this, the authors present a design space around the dimensions of "agency" and "interest" with four user engagement frames to articulate twelve different user roles. Based on that we don't believe that the future of semi-public multi-user interfaces like IIRs lies in VR, but rather in AR. Nevertheless, also for AR solutions it has to be worked on showing other users and their interaction with the information as well as awareness information about the activities of others in order to avoid an exclusion of (avatars of) remotely present knowledge workers. We already addressed this design issue of providing a "social place" in the previous sections (particularly in Section 2.3.2).

To summarize, we envision the following developments included in future IIR solutions to foster a common ground, awareness and appreciation:

- designing AR in a way users can see other users at the same place,
- showing remote users in AR based on different types of "nearness", e.g. working on same topic, working in same project, being physically close,
- synchronizing places – e.g. showing the same information to users that are present at a place (physical or virtual),
- using holograms to include avatars of remotely present knowledge workers in physical places for users that are currently not wearing the AR glasses in order to not exclude them from the full social experience.

Making the situated social place accessible for remote users – by showing remote users in AR or by synchronizing places – makes the big potential of this feature of IIRs available in future (hybrid) scenarios.

If the large screen version of IIRs for communicating information will vanish, this opens the question, how social places will be provided. Regarding that, we envision that the information supply via AR will be extended with pieces of information about people providing function via other means, e.g. holograms, screens showing remote users, or AR displays pointing to other users.

6 Conclusions

Assuming that human knowledge workers will still be relevant in the future, there will also still be a need for IIRs covering the same functionalities as discussed in Section 2.3: providing awareness, supporting serendipity and building a situated social place for matchmaking and informal communication.

The future of IIRs in our vision will be a dynamic blend of digital and physical experiences, personalized and social. Using the developments in HCI – particularly towards new display possibilities and new interaction possibilities, there will be multimodal interfaces, haptic feedback and integration with the Metaverse. The user interface might move some from real world installations to presentation via AR including a higher grade of personalization.

Due to the increasing hybridity of work, presenting information about co-workers will be more important than it is today and again, different ways will be used to do so, from annotations in AR via avatars on screens up to representations of the people via holograms.

As technology continues to evolve, IIRs will adapt and transform, offering new ways to support knowledge workers in their daily tasks. Among others, IIRs may become central hubs for collaboration.

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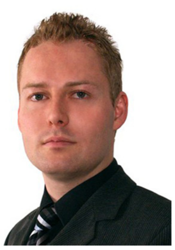

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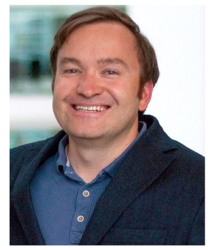

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