A Design Framework for Awareness Cues in Distributed Multiplayer Games

Conference Paper · April 2018

DOI: 10.1145/3173574.3173817

A Design Framework for Awareness Cues in Distributed Multiplayer Games

Jason Wuertz[1], **Sultan A. Alharthi**[2], **William A. Hamilton**[3],
Scott Bateman[1], **Carl Gutwin**[4], **Anthony Tang**[5], **Zachary O. Toups**[2], **Jessica Hammer**[6]
[1] HCI Lab, University of New Brunswick, Fredericton, NB, Canada
[2] Play & Interactive Experiences for Learning Lab, New Mexico State University, Las Cruces, NM, USA
[3] Interface Ecology Lab, Texas A&M University, College Station, TX, USA
[4] Interaction Lab, University of Saskatchewan, Saskatoon, SK, Canada
[5] RICELab, University of Calgary, Calgary, AB, Canada
[6] HCI Institute / Entertainment Technology Center, Carnegie Mellon University, Pittsburgh, PA, USA
jwuertz@unb.ca, salharth@nmsu.edu, bill@ecologylab.net, scottb@unb.ca, gutwin@cs.usask.ca,
tonyt@ucalgary.ca, z@cs.nmsu.edu, hammerj@andrew.cmu.edu

ABSTRACT
In the physical world, teammates develop situation awareness about each other's location, status, and actions through cues such as gaze direction and ambient noise. To support situation awareness, distributed multiplayer games provide awareness cues—information that games automatically make available to players to support cooperative gameplay. The design of awareness cues can be extremely complex, impacting how players experience games and work with teammates. Despite the importance of awareness cues, designers have little beyond experiential knowledge to guide their design. In this work, we describe a design framework for awareness cues, providing insight into what information they provide, how they communicate this information, and how design choices can impact play experience. Our research, based on a grounded theory analysis of current games, is the first to provide a characterization of awareness cues, providing a palette for game designers to improve design practice and a starting point for deeper research into collaborative play.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Awareness cues; situation awareness; workspace awareness; game design; distributed multiplayer games.

INTRODUCTION
Teams working together in the physical world develop situation awareness [13, 14] about teammate location, status, and actions through cues such as body language, gaze direction, and ambient noise [29, 31, 61]. *Distributed* games help players coordinate by providing *awareness cues*—information that systems automatically make available to collaborators to support cooperative actions [44]. Distributed games are played together by players on separate devices typically arranged so that players cannot see each others' screens. Thus, it is primarily through awareness cues that teammates' status, characteristics, actions, experience, etc. are represented and understood. Because *gameworlds*, the virtual worlds that players experience as the interface to games [35], are artificial and lack the sensory cues that make coordination as natural as it is in the physical world, awareness cues must be designed to provide the right information at the right time. Game designers have additional latitude to create detailed and complex representations of actions and events that occurred in past, present and future, and are not limited only to approximating cues that exist in the physical world.

Since teammates in distributed games are largely experienced through awareness cues, the principal challenge for game designers is to create tools that will provide the right information at the right time [62]. The design tension is to balance this information with ensuring that the game remains challenging, so giving a player omniscience is undesirable. If a game designer provides too little information, coordination will be cumbersome, awkward, and slow; if they provide too much information, cues could be overwhelming, difficult to learn, and distract from gameplay. On the other hand, some games opt to purposely limit awareness cues to increase uncertainty and realism, and some even provide this as a separate game mode (e.g., *Left 4 Dead 2* (*L4D2*) [G21], *Rainbow Six: Siege* [G19]). In contrast, other games try to raise the ceiling on performance by providing many rich awareness cues and tools, which can be initially overwhelming and increase the game's learning curve (e.g., *League of Legends* (*LoL*) [G17], *Dota 2* [G23]). Despite the importance of awareness cues in distributed games, there is currently little information about what information game designers provide, how it can be provided, and what trade-offs might exist with particular designs.

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

ISBN 978-1-4503-5620-6/18/04. . . $15.00
DOI: https://doi.org/10.1145/3173574.3173817

Using a grounded theory approach, we examined 24 games, selected for maximum variability, from which we identified and analyzed 100 awareness cues. Our research provides a characterization of the range of awareness cues currently in use through game mechanics, interface components, and other information displays. We do this by first articulating the information made available through awareness cues to teammates. Second, we describe the essential design dimensions of awareness cues and how they make teammate information available. Third, we discuss potential consequences for games and play experience when particular design choices are made.

While prior work has considered synchronous verbal communications [8,56,67] and cooperative communication mechanics (game mechanics invoked by players to communicate with one another) [37, 60, 64, 70], our work focuses on the understudied tools and techniques that games use to support coordination, which are made available to players without explicit effort.

Building on previous work in awareness, this work makes two main contributions. First, we provide a palette for game designers and researchers to identify and devise new awareness cues depending on the game experience they want to target. We expect that users of games (players and viewers) influence how cues should be designed and also consider how players adapt their play experience through cues. Second, we provide a starting point for future research and for informed design practices around awareness cues in online games, and in groupware more broadly.

Organization
We first synthesize background on awareness and related awareness frameworks to motivating the present work, then describe our grounded theory approach and our search and selection strategy. We then present our design framework that classifies cues by the information they provide and how they convey that information, discuss how the framework aids designers in explaining their cues and surfacing them for analysis, and identify implications for designers and researchers.

Our work uses games, game mechanics, and game interfaces as primary data sources, which form a Ludography. Games that are discussed but are not a part of the dataset appear in References. When games from the Ludography are cited they are prefixed with a "G" (e.g., [G6]).

RELATED WORK
In this section we provide background on awareness, with a focus on games. We then discuss prior frameworks and identify the gap that we address—an improved understanding of awareness cues in distributed multiplayer games.

Awareness and Awareness Cues
Awareness provides people with knowledge about the state of the changing environment around them [24]. *Situation awareness* is the ability to understand a complex situation and predict its future states in order to make decisions [13]. A high level of situation awareness supports decision making, enabling an actor to identify one or more correct courses of action. In distributed teams, awareness of teammates' status and activities is critical to coordinate activity and avoid interference [14]. To maximize performance, teams organize their activities and synchronize their effort [46, 49].

As teams develop *shared mental models* [19], they are able to improve their situation awareness [13, 14], which allows them to coordinate more efficiently [66]. This occurs because as teams become more efficient, they reduce their reliance on verbal communication [39, 65], shifting to a mode of implicit coordination [15, 16, 63]. Successful implicit coordination means that team members can communicate less and readily make use of cues from their working environment.

Although team or group awareness is easily maintained in co-located collaborative environments, it is more difficult in remote collaboration [26]. Hence, groupware research has focused on interface techniques that facilitate communication and increase group awareness [24]; i.e., awareness cues. In our work, we use the definition for awareness cues put forward by Oulasvrita who described them as ... *any signal or symbol or mark in the user interface—typically textual, graphical, or auditory—the content of which is produced (or influenced), in real time, by the actions or properties of a remote person.* [44]

Awareness in Cooperative Games
Cooperative play engages two or more players in challenges that require them to work together to defeat a common opponent or the game system (e.g., *L4D2* [G21], *Portal 2* [G22]) [18, 38, 72]. Players want and need the ability to collaborate and share relevant information to have fun and to succeed [17, 36]. Players communicate through many channels: verbally through voice [56] or text chat; or using specialized tools such as virtual gestures, pings, or annotations [60, 70]. Prior research has investigated how such communication channels are used in games [60, 70], how they provide a shared awareness of teammates [8], and what other communication channels exist in cooperative games [60]. However, there is little work investigating how awareness cues that are automatically shared by the game support cooperative play.

Prior Awareness Frameworks
Because of the importance of awareness in remote collaboration, there has been substantial research into frameworks that describe its nature and characteristics [8, 24–27]. For example, studies have investigated team awareness in collaborative environments, including shared workspaces [12, 24, 25, 46], software development teams [26, 54], and gaming [8, 43, 58].

In co-located and distributed collaborative environments, people need to gather information from the environment around them and make sense of it to maintain situation awareness. In these collaborative environments, several tools and widgets are used to help maintain awareness [26]. Research on workspace awareness has proliferated in the field of computer-supported cooperative work and helped address several coordination challenges [24, 26]. This prior research provides insights into how to design tools to support awareness and collaboration.

Gutwin and Greenberg define Workspace Awareness (WA) as *the up-to-the-moment understanding of another person's interaction with the shared workspace* [25, p. 412]. They proposed a framework that provides designers with a common understanding of how to support awareness and foster collaborative activities. The framework is structured around three questions: WHO we are working with; WHAT they are doing; and WHERE they are working. WA supports successful collaboration and helps reduce the effort needed to coordinate tasks and resources. We focus specifically on distributed multiplayer games, which are a form of workspace.

Cheung et al. [8] classified awareness cues in co-located games. Co-location allows players to, for example, look at one another's screens or overhear one another to gain and maintain awareness. However, this is not possible in distributed games as remote players cannot view others' displays. Thus, these cues need to be designed specially for remote players in order to provide them with needed awareness information.

A Framework of Gamespace Awareness

While the existing WA literature is extensive, Teruel et al. found that gameplay involved a superset of activities from those observed in group work [58]. Seeking to unify WA with observed game activities, including social and group dynamics, they developed the Gamespace Awareness (GA) framework through a thematic analysis of previous workspace awareness research. GA frames existing awareness research in the awareness questions introduced by games and considerably expands on Gutwin's WA framework. Furthermore, GA includes social and group dynamic awareness (group membership, group awareness, roles and communication awareness) necessary for multiplayer games. We use GA as a reference frame for understanding and classifying awareness cues.

One shortcoming of GA is that it does not specifically identify *how* awareness can be provided in cooperative games. Therefore, we develop a design framework to describe how to develop cues that encode and represent awareness information.

METHODOLOGY

We conducted a grounded theory study of cooperative games to identify and characterize the range of awareness cues currently used in these games. Grounded theory is a set of qualitative practices aimed at exploring and characterizing a new domain by developing a related set of codes from data [21, 22]. It is a common methodology for extracting structured frameworks from video game components and mechanics [60, 68]. In grounded theory, researchers build up codings and characterizations from a series of rounds of data collections and open coding, followed by structuring. The proposed framework was the result of a fairly standard Glaserian approach to grounded theory [20–22]. This is in similar style to previous studies (e.g., [60, 69]). Our process involved three phases, with frequent iterations both within and between phases:

- Phase 1: finding and selecting distributed, cooperative games via an iterative inclusion criteria;
- Phase 2: initial observations and open coding; and
- Phase 3: revising the coding scheme to develop axial codes.

During each phase, the researchers engaged in discussions to explore the relationship between the examples and their codes, the emergent concepts, and the initial awareness cues.

Phase 1: Finding and Selecting Games

Our iterative process started with a collection of games researchers were familiar with. However, not all distributed games included awareness cues, so discussion and iteration was required. Games with awareness cues were recorded in a spreadsheet that was updated frequently during discussions. These discussions also resulted in a set of inclusion criteria that were applied to the existing list as well as future additions to determine if games fit the dataset:

- the game must include a cooperative play mode;
- the game must automatically render a player's state or perception to another cooperating player (i.e., information should come from a teammate not an enemy); and
- the game must be designed for distributed play.

Since our goal was to maximize variability in the set, we excluded new games that were similar to ones in our existing set. Our final data set includes 24 games, drawn from a range of genres, including first-person shooters (FPS), multiplayer online battle arenas (MOBAs), real-time strategy (RTS), and role-playing games (RPGs). Co-located cooperative games were excluded to focus on awareness cues that were designed without any additional local context.

After initial coding (Phase 3) researchers often returned to this phase seeking out specific types of cues that were hypothesized about as potential codes and dimensions emerged. This also resulted in the following natural stop criteria:

- the absence of games that demonstrate new awareness cues
- existing axial codes and design dimensions did not suggest new potential cues that we did not have in our dataset

Phase 2: Initial Observations and Awareness Information

As games were added to the dataset, each was evaluated for any awareness cues that it might provide. Data were drawn from personal play experiences and observations of players, both in-person and through gameplay videos from Internet sources (e.g., Let's Play videos on YouTube and Twitch). As games were added to the dataset, we identified awareness cues and collected the following details: game name, genre, player count, co-op / competitive mode(s), awareness cue description, screenshot, and comments.

For each cue, we identified whether and how each addressed awareness questions, such as: WHO players are playing with, WHAT they are doing, WHERE they are in the gameworld, and HOW these events would occur. As more games were added, we began to see saturation in the dataset: new games were not adding new insights. Consequently, the final dataset contained 100 cues from 24 games. While there are other games that fit the inclusion criteria, we expect there to be substantial overlap.

Phase 3: Axial coding and design dimension classification

Through a series of discussions, we iteratively identified potential design dimensions. At each stage, we conceptually decomposed the cues using descriptive labels, and determined their positions on each dimension. We refined these dimensions until we had eliminated redundant dimensions, and the dimensions remained relatively stable as we added new games to the set. During this process, we noted any implications and trade-offs we identified based on the awareness interpretations of the cues and their design dimensions.

THE DESIGN FRAMEWORK FOR AWARENESS CUES

Awareness cues encode information that games make available to players to support cooperative gameplay. Awareness cues address individual questions (e.g., WHERE is my teammate? WHAT are they doing?), and are often combined into larger tools and widgets such as character embodiments[1], hit point (HP) bars, usernames, and user icons (Figure 1).

While work has been done to provide a unified [58] framing of awareness in games, existing frameworks provide little insight into the design of tools that support awareness. To fill this gap, we present a framework for awareness cues in distributed games. To understand awareness cues and the proposed design framework, we consider two perspectives:

1. what information awareness cues provide; and,
2. the design dimensions behind these awareness cues.

For the former, we consider how cues answer questions related to awareness (e.g., state of my teammates); for the latter, we develop a set of properties that describe interface elements of cues (e.g., animated icons with status information). Our discussion of current awareness tools in games is not exhaustive and should be seen as an exploration of common tools in games and the awareness information they communicate.

The Information Provided by Awareness Cues

Prior research on WA [24] and GA [58] identified four types of information that team members use when collaborating:

- WHO? – Presence and identity
- WHAT? – Status and tasks and social structure
- WHERE? – Location, positioning, and gaze
- HOW? – Communicating the way important events occur

In the following sections we use this organizational framework to provide an overview of the awareness information provided by current distributed multiplayer games. For each question, we indicate the range of ways that the information is conveyed, introduce game design factors that relate to that awareness element, and discuss temporal aspects to the questions.

WHO? – *Presence and Identity*

In traditional groupware systems, identity information is relatively static; while team composition may change as people come and go, individual members' names and capabilities do not. Many distributed multiplayer games are fundamentally different: although *players* may be continuously present, their embodiment (i.e., their in-game avatar) may go in and out of existence in the game world multiple times during a single play session as they die and respawn. Thus, WHO information is characterized both by identity of the player as well as the avatar the player embodies.

[1]*Embodiments* are how players exhibit agency in gameworlds (e.g., avatars or cursors) [2, 53].

Figure 1. Two examples of WHO information (among others). A: Diegetic presence and identity information through embodiments in *Team Fortress 2* [G20]. From the perspective shown, the player can tell what classes teammates are playing, what weapons they are using, and the health of the character in the crosshairs. B: X-ray vision of teammates in *L4D2* [G21] demonstrates how games solve the problem of obstructed vision of teammate embodiments.

Presence and identity of *players* is typically shown in non-diegetic displays, such as a list view, which shows the identity of teammates and sometimes also shows information about their embodiments (i.e. dead or alive). Some games show this team list in a fixed location on the interface [G3, G6, G7, G21] (as seen at the bottom of Figure 1.B), while others allow this information to be called up on demand (i.e. holding Tab in *Overwatch* shows Figure 2.B).

A player's embodiment in the game is the primary way that others perceive the player's (and the avatar's) presence. WHO information about presence can be shown diegetically[2] by their existence. Additional information about the character's abilities and roles is also often shown diegetically (e.g., via the character model or adornments on the avatar). Finally, the player controlling the embodiment is often shown using a text label above the avatar. Since players can change their avatar through a gameplay session, tracking this WHO information is a critical part of successful team coordination.

This embodiment-based display of WHO information can be limited by the player's field of view, distance, or occlusion. In a departure from the physical world, game designers address this problem in two ways: with markers on or over an embodiment (e.g., *Tribes: Ascend* [G13], *Team Fortress 2* [G20]), or sometimes by showing outlines of teammates *through* gameworld obstacles (e.g., Figure 1.B).

WHO information can also be found elsewhere in the interface. A radar view that primarily shows locations (as described below) also implicitly indicates which teammates' embodiments remain in the game. Some games identify fellow teammates using unique icons. We also see authorship awareness in some places. For example, some games show an icon in the interface or above the avatar to indicate who is talking.

WHAT? – *Status, and Tasks & Social Structure*

Status: As with identity, games are typically concerned with the in-game embodiment's status, rather than that of the player.

[2]"The narrative presented by a cinematographic film or literary work; the fictional time, place, characters, and events which constitute the universe of the narrative." [45].

Embodiments in games have several attributes that vary during a game (e.g., HP, powers, equipment), and these elements are often part of a game's awareness displays.

Many games present multiple pieces of status information as augmentations around or above a player's avatar. For example, *Realm of the Mad God* (*RotMG*) [G24] displays an HP bar below embodiments, a line of icons indicating positive or negative effects currently in place for the embodiment (e.g., powerups, detriments), and numbers showing the rate of HP and mana regeneration (Figure 3.D). Although previous work has shown that people are able to interpret a large number of these augmentations [53], *RotMG* is a good example of how visual effects can quickly clutter the display when there are many embodiments in view.

Status information can also be conveyed through automatic chat messages. For example, when an *Overwatch* embodiment reaches a critical health level and the player requests healing by pressing a button, a "Critical Health!" phrase is automatically added to the usual "I need healing!" chat message. We consider this an awareness cue as it automatically supplies extra information about this teammate to another player.

Some status information is also presented about the players. Nickname display is shown in most games and is often part of the avatar or player-list augmentation (e.g., Figures 1.A; 3.C; 3.D); player experience is less common, but is important in some games because experience level determines how players will form their strategy. One example of this is the "level borders" decoration in the *Overwatch* [G6] player list: as players demonstrate skill, their portrait is given additional levels of decoration (e.g., Figure 2.B).

Tasks and social structure: Maintaining awareness of other players' actions, activities, and intentions is a critical part of successful teamwork. Much has been written in CSCW about how coordination depends on an understanding of what others are doing—for example, the idea of *social protocols* that act as access-control mechanisms over shared resources [23]. Information about what others are doing can include a character's low-level activity (e.g., their movements and detailed actions), their higher-level activity (e.g., the task they have taken on in the game), or their plans for the future (e.g., a division of labor for a future group activity). Given the importance of this type of awareness information, and the many examples of augmentations and external widgets for showing other kinds of awareness, it is somewhat surprising to see how reliant games are on in-view representations of activity, and voice communication [56, 67]. That is, the primary vehicles for conveying information about what a person is doing are in the embodiment itself, and through the player's spoken messages.

There is, of course, much that can be conveyed about activity through an embodiment—for example, where an embodiment is (and where they are going) in the gameworld gives strong clues as to a player's destination and task (particularly in games that are oriented around location-based objectives); similarly, what equipment they are holding (e.g., a sniper rifle) and what they are doing with that equipment (e.g., shooting) clearly shows their current activity. In addition, many games' visual representations of embodiment actions and equipment are often highly recognizable—for example, the weapons used in *Team Fortress 2* [G20] are large and visually obvious (Figure 1.A); similarly, many actions have characteristic visual effects, such as a smoke trail from firing a rocket, or a particle effect from casting a spell (Figure 2.A). However, relying on embodiments to convey awareness information has the limitation that characters must be in view. Additionally, some games provide an awareness of the capabilities of teammates. For example, in *Dota 2* [G23] players can see detailed information regarding the spells and abilities of their teammates.

Figure 2. A: Characteristic visual effects of different embodiment actions in *LoL* [G17]. B: Character icons in *Overwatch* [G6]: the borders represent player experience whiel silver icons represent skill. C: Automatically amended chat messages in *Overwatch* [G6] indicating of the severity of a player's request.

Some games provide a kind of automatic commentary in the team chat channel that provides information about others' activities. For example, many games produce text or voice notifications when teammates have reached a new level of achievement (e.g., "NickFury8 is on a scoring streak!" or "NickFury8 has levelled up!") [G14, G17, G23]. However, the automatic display of information about activities, tasks, and future plans is still limited, which means that many games must rely on players talking to each other through verbal channels (voice or chat) about what they are doing. It may be that planning and executing coordinated group strategies in games are complicated enough that automatic displays cannot provide enough information, and so human communication is necessary. This is an area where experienced teams rely on practice and prior planning—that is, if a team already knows what to do when executing a group action (because they have practiced it many times), people are much less dependent on up-to-the-moment displays of others' activities. Such a change represents a shift toward implicit coordination [15, 16, 63].

WHERE – *Location, Positioning and Gaze*

Conveying other players' locations in the gameworld is primarily accomplished in one of three ways: first, within the field of view of the player; second, through radar (or bird's eye)

Figure 3. A: "Stun bar" showing when an effect will finish in *Dota2* [G23]. B: A visualization of the future range of a spell in *Dota2* [G23]. C: "Kill feeds" in *Overwatch* [G6]. D: Status awareness cues over embodiments in *Realm of the Mad God* [G24].

views[3]; and, third, through abstract widgets such as icons on a compass. For example, in *PlayerUnknown's Battlegrounds* [G7] players can see map markers for their teammates in a compass at the top of the screen (see Figure 5.C).

Some games make a considerable effort to increase the visibility of location information—for instance, by highlighting or outlining embodiments so they are visible through obstructions (e.g. Figure 1.B), or by simply indicating their location via icons when a straight view of them is impossible. Additionally games may display icons on the edge of the screen when the other players' embodiments are outside of one's viewport. Beyond this, some games append distance information about other players next to the icons or names. Another common widget used in multiplayer games represents an abstract "birds eye view" of the environment in which other players' embodiments are represented by icons or glyphs.

HOW – *Communicating the Way Important Events Occur*

HOW actions and events are being accomplished or were accomplished in the gameworld can be critical information. In particular, we note that many games are not sufficiently complex to warrant HOW information. Awareness cues can provide immediate notifications (e.g., kill feeds in Figure 3.C), but if they persist they can also convey information about past events. Whether a HOW cue that persists provides present or past awareness depends on when the player notices it.

One common example are the kill feeds common in player versus player games. These provide a log of player deaths and often how the death occurred (Figure 3.C). In such games, it is critical for players to maintain an awareness of task history, which aids understanding of teammates' current capabilities (for example, if a teammate has just killed an enemy that has a special ability, this ability will not be available to the opponents for some time). This kind of HOW awareness is most common in adversarial games where maintaining an awareness of how your teammates have been affected by enemies (and vice versa) is important.

Temporal Component: Past, Present, and Future Awareness

Situation awareness requires the integration of past and present events in order to predict future events [13,14]; thus, it is necessary to maintain an awareness of all three temporal states (past, present, and future). Indeed, all of the awareness elements discussed above have temporal components.

Historical traces and change awareness have been explored in other areas for many years (e.g., [1, 30, 55]). Some games represent the past through persistence of changes to the gameworld. This is integral to construction-based games like *Minecraft* [40] (where the purpose of the game is to change the world), but has also been used in other game genres such as shooters, many of which make certain effects of acting in the world persistent (e.g., in the *Halo* series [G8], bullets create holes in walls and battle traces such as blood spatters persist for several minutes). These persistent visuals can be used by other players to determine what has occurred in a particular location (and can also be repurposed as an emergent CCM—such as firing a bullet to mark a particular location).

Second, several games provide indications of future activity, including displays such as effect timers and spawn timers. For example, *Dota2* [G23] shows "stun bars" that indicate the time when a stun effect will wear off (Figure 3.A); several other games use similar spawn timers (both for teammates and monsters) and almost all player-versus-player games inform the team of how long a teammate will be dead before respawning.

Third, games often provide automatic chat messages that provide information about past and future events. Kill feeds are nearly ubiquitous in player-versus-player games (Figure 3.C) as are voice prompts and/or head-up display (HUD)[4] messages reporting on the state of the current match (e.g., "Only 15 kills remaining!" [G6] as a team nears a quota to win).

Design of Awareness Cues

After a designer decides what awareness information to include, they must decide how that information should be represented. Above, we presented what information games share in order to support situation awareness, with examples. Awareness tools and widgets are often made up of several awareness cues working together or providing complementary information. For example, Figure 3.A shows how multiple cues can be combined. In this case it consists of text, a progress bar, an embodiment animation and an icon animation.

Rather than exhaustively list individual awareness cues and relate them to widgets, our analysis instead allows us to characterize the design space of awareness cues. This presentation allows game designers to better understand and differentiate awareness cues, and to identify how different decisions in the

[3]Radar views show the relative locations of cooperating players (and, usually, enemies). Some are combined with a mini-map showing topology and/or points of interest.

[4]The HUD is an information overlay through which the player experiences the game.

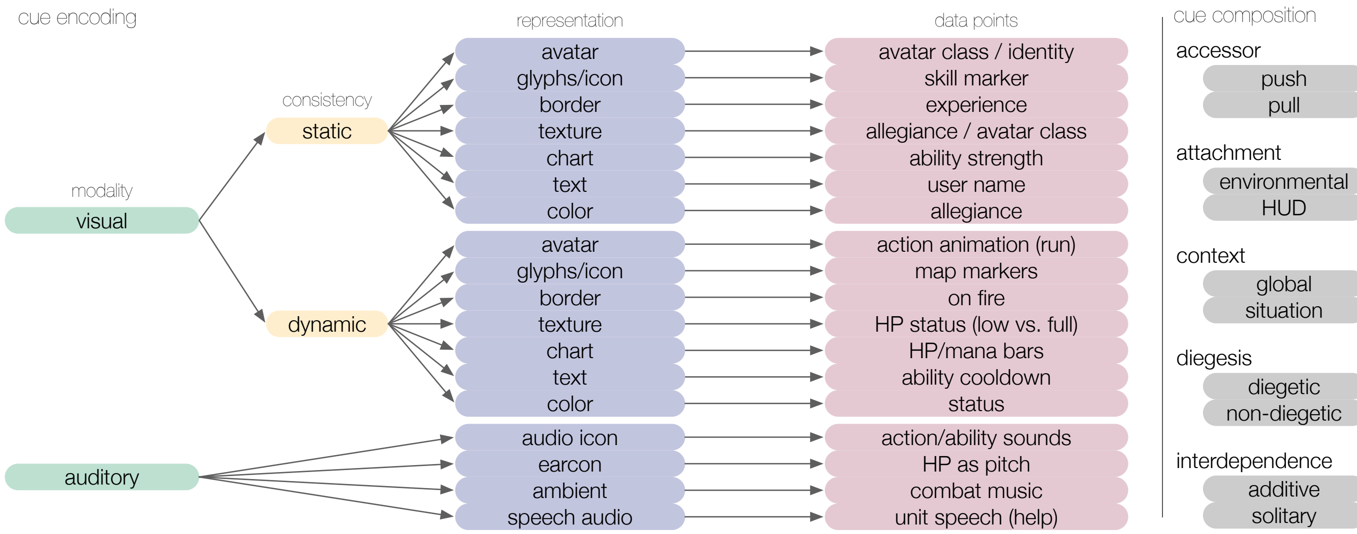

Figure 4. A thematic tree describing the framework for awareness cues in multiplayer games. See Table 1 below for an application to example cues.

Figure	Encoding			Composition				
	Modality	Consistency	Representation	Accessor	Attachment	Context	Diegesis	Interdependence
2.B	Visual	Dynamic	Icon	Pull	HUD	Global	Non-diegetic	Solitary
3.A	Visual	Dynamic	Chart	Push	Environmental	Situational	Non-diegetic	Additive
3.A	Visual	Dynamic	Avatar	Push	Environmental	Situational	Diegetic	Solitary
5.B	Visual	Dynamic	Chart	Push	Environmental	Global	Non-diegetic	Solitary

Table 1. Example awareness cues categorized using the framework. Figure 2.B shows a team list accessed via holding Tab in *Overwatch* [G6]. Figure 3.A shows a progress bar and embodiment animation respectively. Figure 5.B a HP bar found in *Dota2* [G23].

space can lead to different designs. Further, this decomposition supports critical practice around design and facilitate the invention of new cues and widgets.

We identified two sets of decisions that must be made when information is represented as a cue. First, awareness information must be *encoded* (i.e., decisions must be made about the cue can be represented). Second, decisions must be made about how a cue can be *composed* (i.e., how individual cues are combined, displayed and accessed).

Cue Encoding

Cue encoding refers to how game designers represent awareness information to be accessed by a player. Our analysis resulted in three decision points in that must be made to encode awareness information as a specific representation, and five further properties of cue composition. Figure 4 displays a thematic tree connected to specific exemplar data points. Also, Table 1 provides illustrative examples from our figures described by their *cue encodings*.

Modalities: refers to the two main sensory channels through which players can receive cue information: *visual* and *auditory*. Many designers (and HCI researchers) are likely familiar with the notion of representing information visually; however, we also found many uses of auditory cues that may be somewhat less familiar (see Figure 4). Visual and auditory cues are often used together and are often so tightly coupled that they might be considered a single cue. It should be noted that while it may also be possible to use haptics to encode awareness information (e.g., a vibrating controller to denote when a player bumps you), we did not encounter any instances.

Consistency: refers to whether a visual cue changes or not. Visual cues can be *static* or *dynamic* cues. Static cues do not change during a game session. For example, a player's username would usually be static throughout a match. Dynamic cues change during the course of gameplay. For example, it is common for HP bars to increase and decrease depending on in-game events. Auditory cues by their nature are dynamic, in that they have a short duration; their pitches and envelopes [4, 5] are modulated to encode information (as described below).

Representation: refers to the specific design that encodes awareness information. Similar to information visualization problems designers are presented with a variety of channels [42] that can encode and communicate different types of data. While there are potentially other possible encodings, Figure 4 contains the specific representation found through our analysis.

While some representations are straightforward and familiar, (e.g., *color*, *text*, *icons*), others warrant further explanation. *Avatar* cues refer to a player's in-game embodiment. For example, an animation showing an embodiment reloading her weapon. *Glyphs* refer to specifically designed visual representations. For example, a triangular wedge glyph on a mini-map is a frequent representation of the location and the direction that players are facing. *Charts* are most frequently seen as simple bar charts to represent health. *Borders* are graphics surrounding other icons, glyphs or avatars. They often represent a secondary attribute of the thing they surround.

While speech and ambient audio cues are straightforward, audio icons and earcons require more explanation. *Audio icons* are short sounds that correspond directly to an action or

Figure 5. A: Avatar allegiance is shown by the characters clothing color in *FIFA 17* [G11]. The arrow is pointing to a diegetic representation of status, low health/injury in this case. B: The dynamic nature of HP bars found in *Dota 2* [G23]. C: In *PUBG* [G7] squad-mate HP bars, activity icons (parachuting) and waypoint colors are shown on the left while the center-top of the players screen shows a compass with the directions of their teammates waypoints. D: Player perception indication in *Overwatch* [G6] via a on-fire border animation. In this case it shows that the player is performing well.

event [4,5] (e.g., a teammate moving close by is represented by a unique character-specific footstep sound in *Overwatch* [G6]). *Earcons* are abstract sounds whose characteristics are varied corresponding to the underlying data they represent, so they can be used to build complex notifications [4, 5]. Learning to identify and make effective use of audio representations is challenging, but useful, for players [34].

Cue Composition

While cue encoding (described above) concerns itself with the auditory and visual representations of awareness information, cue composition describes how the cues fit into the game experience. It should be noted that some encoding combinations and compositions are unlikely or impossible. A non-diegetic, dynamic avatar awareness cue makes little sense. For example, it is unclear how (or why) one would make a game embodiment move without it being considered part of the embodiment's narrative experience of the gameworld.

Cue Accessor: refers to the means by which a player can access an awareness cue. Cues can be either *push* or *pull*. *Pull* cues refer to cues that are not initially available, but can be made visible or triggered through some input action by a player (e.g., players view the *Overwatch* [G6] scoreboard, Figure 2.B, by holding the TAB key). By using *pull* accessors, designers can enable access to a large amount of information that would not be otherwise feasible to display.

Push cues are information that is provided without player input. Here designers must balance the needs of players. Information that players must be aware off constantly or that has important time constraints may best be *pushed* to players, while information that is less critical can be *pulled*. Oftentimes games combine cues that *push* coarse information and allow more fine-grained details to be *pulled* through interaction (e.g., seeing a player's character name over their avatar, mousing over it provides more detailed status). *Pushed* awareness cues are very common, and include passive displays such as HP bars, usernames, or the avatars themselves.

Cue Context: refers to the time at which a cue is visible or available, and its duration. For many sufficiently complex games making all information available at all times would be overwhelming and provide little utility. Designers typically limit cue availability, allowing only certain cues to persist for the entire game, while other cues are made available based on particular events occurring. Cues that are *global* are available at all times; these cues tend to persist and can be accessed at all times. Global cues typically contain information that needs to be frequently accessed, or critical information that could be needed at any time (e.g., HP bars, team lists).

Situational cues provide information after certain events, because it is superfluous (and even distracting) until those events occur. Typically, situational cues are ephemeral and only persist while the information is relevant. For example, stun animations in *Dota2* [G23] are situational as they are only shown when a teammate is in a stunned state (Figure 3.A).

Cue Diegesis: describes how the awareness cue relates to the narrative gameworld [32]. If an awareness cue is perceivable by in-game characters (as if the embodiment were a living entity in the gameworld) it is *diegetic*. If the cue is instead part of the interface or non-visible to the characters, then it is *non-diegetic*. A common example of diegetic cues are speech audio uttered by an in-game character (e.g., in *L4D2* [G21], characters automatically announce to teammates when they find a stash of ammo: "Ammo Here!"). However, cues that are placed in the environment (i.e., attached to an in-game object; see Cue Attachment below) are not necessarily diegetic (e.g., a stun bar in *Dota 2* [G23] is placed over the head of an avatar but is not perceivable by characters). Using diegetic cues can increase the feel of realism in a game, but a cue must make sense within the theme and narrative of the game.

Cue Interdependence: describes the relationships that individual cues can have. *Solitary* cues exist independently of other cues, providing a sole source of information. For example, HP bars provide information on their own. However, individual cues are often combined making them *additive* cues. Figure 5.D shows the "On Fire" border around the identity avatar of the player in *Overwatch*. This cue would not make much sense without the identity cue it surrounds.

Cues frequently provide important information and aid in the interpretation of another related cue. For example, Figure 5.B shows how a numeric representation of a player's HP enhances the already-present HP bar below it. Individual cues that provide redundant information are considered additive, since this dual representation of the information frequently changes the nature of the cue (for example, by making the awareness information more salient).

Cue Attachment: refers to the placement of cues relative to the interface: they may either be connected to the HUD (so, relative to the screen) or embedded *in* the gameworld through environmental cues. Environmental cues can make critical information fast and easy to access (especially in time-sensitive situations; e.g., HP bars during a team fight). However, cue placement must be done carefully, while players can learn to recognize and understand a larger number of cues attached to in-game objects or characters, these can become distracting and can be overwhelming for novices [2, 53].

Designers often leverage the HUD as a means to offload some of this information. HUD cues are a part of the interface and are typically in a fixed location. Diegetic cues may appear in the HUD or the environment [32]. Diegetic HUDs will only appear when the player's embodiment in the gameworld would have the same experience (common in FPS games where embodiments can wear head-mounted displays).

DISCUSSION

Our framework provides a toolbox for game designers to tackle common awareness challenges in multiplayer games. In this section we discuss the implications of the design framework for several design tensions faced by game designers: fun vs. challenge, novices vs. experts, and streamers vs. their audiences. Further, we discuss these implications in relation to game designers and games researchers.

User Characteristics

Players and viewers (collectively users) bring different concerns for the game designer. We describe how these characteristics impact and are impacted by awareness cue design.

Novices and Experts

A hallmark of experts in a domain is "chunking," the ability to recognize underlying patterns in an apparently chaotic situation [6]. Complex awareness cues that are impenetrable to novices can be not only interpreted by experts, but interpreted quickly and efficiently. Novices, on the other hand, may be aware of the cue but not able to interpret its meaning; they may get little practice with *situational* cues that arise infrequently, and they may not realize that they can activate cues accessed through a *pull* accessor. Designers must consider how to train novices in the effective use of awareness cues and scaffold their transition to expertise.

Viewers as Stakeholders

Many players learn to play new games by watching videos and live streams [7, 50]. However, other viewers in the same audience may already be experts. In designing cues, designers must therefore consider how they can be interpreted by game *viewers* at varying levels of expertise as well as by players. Since viewers cannot control where the player is looking or what cues they choose to display, *environmental* and *pull* cues may introduce particular challenges for streaming gameplay. At the same time, cue designs that make for good viewing are not necessarily the ones that make for high-quality play.

Game Literacy

Games within a genre often share conventions for conveying information, such as HP bars. Understanding and reproducing these conventions is part of what it means to be literate in games [52]. However, these conventional/generic design patterns may or may not serve the designer's goal for a specific game. Our framework allows designers to analyze and characterize existing patterns of awareness cues, and to identify the most productive axes along which to diverge from a conventional approach.

Cue Modality

Our framework enumerates different *representations* of awareness cues, such as visual, auditory, and haptic. Game designers must choose not only in which modality to provide awareness cues, but also how many. Providing cues in all available channels can accommodate the broadest range of play styles, such as players who prefer to play with the sound off or who do not have haptic controllers. However, information provided across multiple modalities can generate unnecessary cognitive load, at the same time, and requiring players to customize the modality in which they access awareness cues could be overwhelming and frustrating unless it is carefully designed [41, 48].

Tolerance for Uncertainty

One function of awareness cues is to manage the level of uncertainty in the game by making certain information salient or showing the player that there is information they don't know [10, 59]. However, different people have different levels of tolerance for uncertainty [33]. A level of uncertainty that is satisfying for one player may be anxiety-provoking for another. Designers must consider whether their awareness cues are useful or frustrating for players.

Player Goals and Motivation

Research on player motivation shows that different players in the same game may have different goals and find different activities satisfying (e.g. [47, 71]). Players may also play for a range of social reasons, such as connecting to real-world or online friends, retaining an online streaming audience, or practicing for professional competition. Awareness cues that address some players' goals may interfere with or even demotivate others. However, unlike with game roles, it is difficult to identify a given player's motivation—particularly as players may play the same game for different reasons on different days. Finally, players' goals may sometimes be transgressive or anti-social [9]. These motivational differences should be taken into account when designing awareness cues.

Adapting the Play Experience

Awareness cues are a key consideration in *how* players approach the play experience, heavily influencing how difficult a game is. Players may deactivate or add awareness cues to their game clients to change the experience.

Adjusting Difficulty

Many games can be played at different levels of difficulty, whether manually adjusted by the player or automatically by the game [51]. Awareness cues are one method for performing difficulty adjustments. For example, many FPS games contain "hard-core" modes in which the amount of awareness information is decreased. Our framework allows designers to articulate the dimensions of the awareness cues that can be manipulated to adjust game difficulty, and to define and study which dimensions they expect to have the highest impact.

Interface and Awareness Mods

Players often customize their user interface experience in games using modifications, or mods [57]. For example, many *World of Warcraft* [G3] mods take *diegetic* game information and convert it to a *non-diegetic* form, while simultaneously taking *environmental* information and placing it in a *HUD*. These choices help players perform their in-game roles more effectively. Designers must therefore consider not only how their awareness cues are designed, but what data they are exposing for players to design their own cues with. Player-generated awareness cues are designed by *players* to serve *player* goals, and can therefore serve as implicit sources of data about what player needs are not being met by the designers' choices.

Asymmetric Gameplay

In asymmetric games, different players take on different game roles or capacities [11, 28]. For example, in many games players can serve as tank[5], DPS[6], or healer[7] [69]. A given piece of information may be much more valuable to the player of one role than another, such as which enemy is doing the most damage or which ally has the lowest health. Designing cues targeted at the responsibilities a given player faces can decrease the amount of clutter and increase the amount of relevant awareness information available. Since the amount of relevant information available to players impacts their chances of success [66] awareness cues must take game roles into account; different player roles may need the same awareness cues expressed differently, or need different cues entirely.

Implications for Game Designers

We demonstrate that our awareness framework ties to awareness-related problems that game designers already face, such as supporting new players and designing for uncertainty. Our framework allows designers to describe their existing problems more effectively, and see how these problems relate to one another. This can help game designers identify design tradeoffs and how they might affect different stakeholders.

Our framework can also help designers iterate and identify design directions that they might otherwise not consider. Using concepts from our framework, they can more carefully articulate the *underlying* rather than only the *apparent* differences between alternative implementations of awareness cues. Consideration of awareness cue design can be incorporated into existing ideation or production methods.

Implications for Researchers

Our work has implications for researchers who want to use games as settings in which to study team coordination or other issues related to awareness. First, our framework can help researchers select appropriate games to use as probes or in studies by providing a way to articulate the awareness cues featured in the game. Second, our work can also inform the design of experimental materials for the study of awareness in games or other CSCW software.

Because we propose a common language for describing awareness cues, we can now articulate differences and similarities between studies allowing us to more effectively survey and combine knowledge from different sources.

CONCLUSIONS AND FUTURE WORK

In this paper we have provided a framework for awareness cues in distributed multiplayer games. In order to effectively collaborate during gameplay, players need information about teammates' identity, location, activities, status, and more. The amount of team awareness information available to players influences the difficulty of coordination and, therefore, play. This means that design choices regarding what, when, and how awareness information is made available directly influence the way players experience the game.

We see this paper as setting out a research agenda for awareness cues in distributed multiplayer games, improving the relevance of our work to both designers and researchers.

First, existing team awareness cues build on common design patterns, both within a particular game genre and across different genres. From this basic language for awareness cues, we can begin to describe the existing set of design patterns for awareness cues that already exist. *Game design patterns* are useful to facilitate and analyze designs [3], and can also be used to identify *negative space* in a design space: places where patterns ought to exist but do not. Game design patterns can therefore improve existing distributed awareness cues as well as driving discovery of new patterns and designs.

We can use these patterns to analyze, improve, and push forward specific aspects of games. One clear axis is looking at different categories of *games*—either looking at specific genres such as MOBAs, or looking at games that share common features, such as turn-based play. Another direction is to compare different categories of *players*, for example understanding what awareness cues are associated with different player roles or how they are deployed differently for experts and novices. Finally, we can look at different types of *information*, such as how nominal versus continuous information is deployed.

Second, we can extend our framework beyond team awareness. When players make decisions, they need to understand their *teammates*, but, their decisions also incorporate information about *themselves*, their *adversaries*, the *environment*, *non-player characters (NPCs)* and the game *system*.

Finally, we expect to bring this work full circle, by applying these insights in other types of distributed workspaces. Specifically, we expect fast-response organizations, like disaster responders, to benefit from this work. Further, we expect other types of groupware (e.g., distributed document editing) can use our work to identify new awareness cues.

The present research contributes to our knowledge of how team members work together, and how teamwork can be supported. We expect our framework to be of value to game designers and researchers, and hope that, through this work, we discover new ways to support team coordination.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), and the National Science Foundation under Grant Nos. IIS-1651532 and IIS-1619273.

REFERENCES

1. Jason Alexander, Andy Cockburn, Stephen Fitchett, Carl Gutwin, and Saul Greenberg. 2009. Revisiting Read Wear: Analysis, Design, and Evaluation of a Footprints Scrollbar.

[5] A character with many hit points that protects other characters.

[6] A character with high damage per second focused on damaging enemies.

[7] A character that focuses on restoring the resources of others.

In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, USA, 1665–1674. DOI: http://dx.doi.org/10.1145/1518701.1518957

2. Peter Bayliss. 2007. Beings in the game-world: characters, avatars, and players. In *IE '07: Proceedings of the 4th Australasian conference on Interactive entertainment*. RMIT University, Melbourne, Australia, Australia, 1–6.
3. Staffan Björk, Sus Lundgren, and Jussi Holopainen. 2003. Game Design Patterns. In *Level Up - Proceedings of Digital Games Research Conference 2003*.
4. Stephen A. Brewster. 2002. Non-speech auditory output. In *The Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications* (2nd ed.), J. Jacko and A. Sears (Eds.). Lawrence Earlbaum Associates, New York, NY, USA, 247–264.
5. Stephen A. Brewster, Peter C. Wright, and Alistair D. N. Edwards. 1993. An Evaluation of Earcons for Use in Auditory Human-computer Interfaces. In *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems (CHI '93)*. ACM, New York, NY, USA, 222–227. DOI: http://dx.doi.org/10.1145/169059.169179
6. William G. Chase and Herbert A. Simon. 1973. Perception in chess. *Cognitive psychology* 4, 1 (1973), 55–81.
7. Gifford Cheung and Jeff Huang. 2011. Starcraft from the stands: understanding the game spectator. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 763–772.
8. Victor Cheung, Y.-L. Betty Chang, and Stacey D. Scott. 2012. Communication Channels and Awareness Cues in Collocated Collaborative Time-critical Gaming. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW '12)*. ACM, New York, NY, USA, 569–578. DOI: http://dx.doi.org/10.1145/2145204.2145291
9. Mia Consalvo. 2009. *Cheating: Gaining advantage in videogames*. MIT Press.
10. Greg Costikyan. 2013. *Uncertainty in games*. MIT Press, Cambridge, MA, USA.
11. Timothy Day, Robert Gray, Weicheng Liu, Stefan Rank, Patrick Dean, Shangyu Chen, and Juan Garzon. 2016. Torchless: Asymmetry in a Shared Screen Dungeon Crawler. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (CHI PLAY Companion '16)*. ACM, New York, NY, USA, 47–53. DOI: http://dx.doi.org/10.1145/2968120.2968123
12. Paul Dourish and Victoria Bellotti. 1992. Awareness and Coordination in Shared Workspaces. In *Proceedings of the 1992 ACM Conference on Computer-supported Cooperative Work (CSCW '92)*. ACM, New York, NY, USA, 107–114. DOI: http://dx.doi.org/10.1145/143457.143468
13. Mica R. Endsley. 1988. Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 32. SAGE Publications, 97–101.
14. Mica R. Endsley. 1995. Toward a theory of situation awareness in dynamic systems. *Human Factors* 37, 1 (1995), 32–64.
15. Elliot E. Entin and Daniel Serfaty. 1999. Adaptive Team Coordination. *Human Factors* 41, 2 (June 1999), 312–325.
16. J. Alberto Espinosa, F. Javier Lerch, and Robert E. Kraut. Explicit versus implicit coordination mechanisms and task dependencies: One size does not fit all. In *Team Cognition: Understanding the Factors that Drive Process and Performance* (1st ed.), Eduardo Salas and Stephen M. Fiore (Eds.). American Psychological Association, Washington, DC, USA, 107–130.
17. Stephen Fiore and Eduardo Salas. 2011. Team cognition and expert teams: Developing insights from cross-disciplinary analysis of exceptional teams. 4 (02 2011), 369–375.
18. Tracy Fullerton. 2014. *Game design workshop: a playcentric approach to creating innovative games*. CRC press, Boca Raton, FL, USA.
19. Dedre Gentner and Albert L. Stevens. 1983. *Mental Models*. Lawrence Earlbaum Associates, Hillsdale, NJ, USA.
20. Barney G. Glaser. 1978. *Theoretical Sensitivity: Advances in the Methodology of Grounded Theory*. The Sociology Press, Mill Valley, California, USA.
21. Barney G. Glaser. 1998. *Doing Grounded Theory: Issues and Discussions*. The Sociology Press, Mill Valley, California, USA.
22. Barney G. Glaser and Anselm Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine Publishing Company, Chicago, Illinois, USA.
23. Saul Greenberg and David Marwood. 1994. Real Time Groupware As a Distributed System: Concurrency Control and Its Effect on the Interface. In *Proceedings of the 1994 ACM Conference on Computer Supported Cooperative Work (CSCW '94)*. ACM, New York, NY, USA, 207–217. DOI:http://dx.doi.org/10.1145/192844.193011
24. Carl Gutwin and Saul Greenberg. 2002. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work (CSCW)* 11, 3 (01 Sep 2002), 411–446. DOI: http://dx.doi.org/10.1023/A:1021271517844
25. Carl Gutwin, Saul Greenberg, and Mark Roseman. 1996. *Workspace Awareness in Real-Time Distributed Groupware: Framework, Widgets, and Evaluation*. Springer London, London, 281–298. DOI: http://dx.doi.org/10.1007/978-1-4471-3588-3_18

26. Carl Gutwin, Reagan Penner, and Kevin Schneider. 2004. Group Awareness in Distributed Software Development. In *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work (CSCW '04)*. ACM, New York, NY, USA, 72–81. DOI: http://dx.doi.org/10.1145/1031607.1031621

27. John Halloran, Geraldine Fitzpatrick, Yvonne Rogers, and Paul Marshall. 2004. Does It Matter if You Don'T Know Who's Talking?: Multiplayer Gaming with Voiceover IP. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems (CHI EA '04)*. ACM, New York, NY, USA, 1215–1218. DOI: http://dx.doi.org/10.1145/985921.986027

28. John Harris, Mark Hancock, and Stacey D. Scott. 2016. Leveraging Asymmetries in Multiplayer Games: Investigating Design Elements of Interdependent Play. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. ACM, New York, NY, USA, 350–361. DOI: http://dx.doi.org/10.1145/2967934.2968113

29. Christian Heath and Paul Luff. 2000. Team work: Collaboration and control in London Underground line control rooms. In *Technology in Action*, Roy Pea, John Seely Brown, and Christian Heath (Eds.). Cambridge University Press, Cambridge, UK, 88–124.

30. William C. Hill, James D. Hollan, Dave Wroblewski, and Tim McCandless. 1992. Edit Wear and Read Wear. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '92)*. ACM, New York, NY, USA, 3–9. DOI:http://dx.doi.org/10.1145/142750.142751

31. Edwin Hutchins. 1995. How a Cockpit Remembers Its Speeds. *Cognitive Science* 19, 3 (1995), 265–288.

32. Ioanna Iacovides, Anna Cox, Richard Kennedy, Paul Cairns, and Charlene Jennett. 2015. Removing the HUD: The Impact of Non-Diegetic Game Elements and Expertise on Player Involvement. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 13–22. DOI: http://dx.doi.org/10.1145/2793107.2793120

33. Jamie Jirout and David Klahr. 2012. Children's scientific curiosity: In search of an operational definition of an elusive concept. *Developmental Review* 32, 2 (2012), 125–160.

34. Colby Johanson and Regan L. Mandryk. 2016. Scaffolding Player Location Awareness Through Audio Cues in First-Person Shooters. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 3450–3461. DOI: http://dx.doi.org/10.1145/2858036.2858172

35. Kristine Jørgensen. 2013. *Gameworld Interfaces*. MIT Press, Cambridge, MA, USA.

36. Yubo Kou and Xinning Gui. 2014. Playing with Strangers: Understanding Temporary Teams in League of Legends. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, New York, NY, USA, 161–169. DOI: http://dx.doi.org/10.1145/2658537.2658538

37. Alex Leavitt, Brian C. Keegan, and Joshua Clark. 2016. Ping to Win?: Non-Verbal Communication and Team Performance in Competitive Online Multiplayer Games. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4337–4350. DOI: http://dx.doi.org/10.1145/2858036.2858132

38. Melissa Loomis. 2015. The rise of online multiplayer games and the collapse of couch co-op. Website. (January 2015). http://gamerant.com/rise-of-online-multiplayer-games-couch-coop/.

39. Jean MacMillan, Elliot E. Entin, and Daniel Serfaty. Communication Overhead: The Hidden Cost of Team Cognition. In *Team Cognition: Understanding the Factors that Drive Process and Performance* (1st ed.), Eduardo Salas and Stephen M. Fiore (Eds.). American Psychological Association, Washington, DC, USA, 61–82.

40. Mojang. 2009. *Minecraft*. Game [PS4]. (17 May 2009). Mojang, Stockholm, Sweden.

41. Roxana Moreno and Richard Mayer. 2007. Interactive multimodal learning environments. *Educational psychology review* 19, 3 (2007), 309–326.

42. Tamara Munzner. 2014. *Visualization Analysis & Design*. CRC Press, Boca Raton, FL, USA.

43. Nicolas Nova, Fabien Girardin, Gaëlle Molinari, and Pierre Dillenbourg. 2006. The Underwhelming Effects of Location-Awareness of Others on Collaboration in a Pervasive Game. In *Proceedings of the 2006 Conference on Cooperative Systems Design: Seamless Integration of Artifacts and Conversations – Enhanced Concepts of Infrastructure for Communication*. IOS Press, Amsterdam, The Netherlands, The Netherlands, 224–238. http://dl.acm.org/citation.cfm?id=1565058.1565077

44. Antti Oulasvirta. 2009. Social Inference Through Technology. In *Awareness Systems: Advances in Theory, Methodology and Design*, Panos Markopoulos, Boris De Ruyter, and Wendy Mackay (Eds.). Springer London, London, 125–147. https://doi.org/10.1007/978-1-84882-477-5_5 DOI: 10.1007/978-1-84882-477-5_5.

45. Oxford English Dictionary. 2017. "diegesis, n.". Dictionary Definition. (June 2017). Retrieved September 15, 2017 from http://www.oed.com/view/Entry/52402.

46. David Pinelle and Carl Gutwin. 2008. Evaluating teamwork support in tabletop groupware applications using collaboration usability analysis. *Personal and Ubiquitous Computing* 12, 3 (01 Mar 2008), 237–254. DOI:http://dx.doi.org/10.1007/s00779-007-0145-4

47. Daniel Possler, Christoph Klimmt, Daniela Schlütz, and Jonas Walkenbach. 2017. A Mature Kind of Fun? Exploring Silver Gamers' Motivation to Play Casual

Games–Results from a Large-Scale Online Survey. In *International Conference on Human Aspects of IT for the Aged Population*. Springer, 280–295.

48. Leah M. Reeves, Jennifer Lai, James A. Larson, Sharon Oviatt, T. S. Balaji, Stéphanie Buisine, Penny Collings, Phil Cohen, Ben Kraal, Jean-Claude Martin, Michael McTear, TV Raman, Kay M. Stanney, Hui Su, and Qian Ying Wang. 2004. Guidelines for Multimodal User Interface Design. *Commun. ACM* 47, 1 (Jan. 2004), 57–59. DOI:http://dx.doi.org/10.1145/962081.962106

49. Eduardo Salas, Terry L. Dickinson, Sharolyn A. Converse, and Scott I. Tannenbaum. 1992. Toward an understanding of team performance and training. In *Teams: Their Training and Performance*, Robert W Swezey and Eduardo Salas (Eds.). Ablex Publishing Corporation, Norwood, NJ, USA, 3–29.

50. Max Sjöblom and Juho Hamari. 2017. Why do people watch others play video games? An empirical study on the motivations of Twitch users. *Computers in Human Behavior* 75 (2017), 985–996.

51. Jan D. Smeddinck, Regan L. Mandryk, Max V. Birk, Kathrin M. Gerling, Dietrich Barsilowski, and Rainer Malaka. 2016. How to Present Game Difficulty Choices?: Exploring the Impact on Player Experience. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 5595–5607. DOI: http://dx.doi.org/10.1145/2858036.2858574

52. Kurt Squire. 2008. Video-game literacy: A literacy of expertise. *Handbook of research on new literacies* (2008), 635–670.

53. Tadeusz Stach, Carl Gutwin, David Pinelle, and Pourang Irani. 2007. Improving Recognition and Characterization in Groupware with Rich Embodiments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. ACM, New York, NY, USA, 11–20. DOI:http://dx.doi.org/10.1145/1240624.1240627

54. Margaret-Anne D. Storey, Davor Čubranić, and Daniel M. German. 2005. On the Use of Visualization to Support Awareness of Human Activities in Software Development: A Survey and a Framework. In *Proceedings of the 2005 ACM Symposium on Software Visualization (SoftVis '05)*. ACM, New York, NY, USA, 193–202. DOI: http://dx.doi.org/10.1145/1056018.1056045

55. James Tam and Saul Greenberg. 2006. A framework for asynchronous change awareness in collaborative documents and workspaces. *International Journal of Human-Computer Studies* 64, 7 (2006), 583 – 598. DOI: http://dx.doi.org/https://doi.org/10.1016/j.ijhcs.2006.02.004 Theoretical and empirical advances in groupware research.

56. Anthony Tang, Jonathan Massey, Nelson Wong, Derek Reilly, and W. Keith Edwards. 2012. Verbal Coordination in First Person Shooter Games. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW '12)*. ACM, New York, NY, USA, 579–582. DOI:http://dx.doi.org/10.1145/2145204.2145292

57. Sean Targett, Victoria Verlysdonk, Howard J. Hamilton, and Daryl Hepting. 2012. A study of user interface modifications in World of Warcraft. *Game Studies* 12, 2 (2012).

58. Miguel A. Teruel, Elena Navarro, Pascual González, Víctor López-Jaquero, and Francisco Montero. 2016. Applying thematic analysis to define an awareness interpretation for collaborative computer games. *Information and Software Technology* 74 (2016), 17 – 44. DOI:http://dx.doi.org/10.1016/j.infsof.2016.01.009

59. Alexandra To, Ali Safinah, Geoff F. Kaufman, and Jessica Hammer. 2016. Integrating Curiosity and Uncertainty in Game Design. In *DiGRA/FDG '16 - Proceedings of the First International Joint Conference of DiGRA and FDG*, Vol. 13.

60. Zachary O. Toups, Jessica Hammer, William A. Hamilton, Ahmad Jarrah, William Graves, and Oliver Garretson. 2014. A Framework for Cooperative Communication Game Mechanics from Grounded Theory. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, New York, NY, USA, 257–266. DOI: http://dx.doi.org/10.1145/2658537.2658681

61. Zachary O. Toups and Andruid Kerne. 2007. Implicit Coordination in Firefighting Practice: Design Implications for Teaching Fire Emergency Responders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. ACM, New York, NY, USA, 707–716. DOI: http://dx.doi.org/10.1145/1240624.1240734

62. Zachary O. Toups, Andruid Kerne, and William Hamilton. 2009. Game Design Principles for Engaging Cooperative Play: Core Mechanics and Interfaces for Non-mimetic Simulation of Fire Emergency Response. In *Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games (Sandbox '09)*. ACM, New York, NY, USA, 71–78. DOI:http://dx.doi.org/10.1145/1581073.1581085

63. Zachary O. Toups, Andruid Kerne, and William A. Hamilton. 2011. The Team Coordination Game: Zero-fidelity simulation abstracted from fire emergency response practice. *ACM Trans. Comput.-Hum. Interact.* 18, Article 23 (Dec. 2011), 37 pages. Issue 4. DOI: http://dx.doi.org/10.1145/2063231.2063237

64. Deepika Vaddi, Zachary O. Toups, Igor Dolgov, Rina R. Wehbe, and Lennart E. Nacke. 2016. Investigating the Impact of Cooperative Communication Mechanics on Player Performance in *Portal 2*. In *Proceedings of Graphics Interface 2016 (GI 2016)*. Canadian Human-Computer Communications Society / Société canadienne du dialogue humain-machine, 41–48. DOI: http://dx.doi.org/10.20380/GI2016.06

65. Roel Vertegaal. 1999. The GAZE Groupware System: Mediating Joint Attention in Multiparty Communication

and Collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, USA, 294–301. DOI: http://dx.doi.org/10.1145/302979.303065

66. David W. Eccles and Gershon Tenenbaum. 2004. Why an Expert Team Is More than a Team of Experts: A Social-Cognitive Conceptualization of Team Coordination and Communication in Sport. 26 (12 2004), 542–560.

67. Greg Wadley, Marcus Carter, and Martin Gibbs. 2015. Voice in Virtual Worlds: The Design, Use, and Influence of Voice Chat in Online Play. *Human–Computer Interaction* 30, 3-4 (2015), 336–365.

68. Dmitri Williams, Nicole Martins, Mia Consalvo, and James D. Ivory. 2009. The virtual census: representations of gender, race and age in video games. *New Media & Society* 11, 5 (2009), 815–834. DOI: http://dx.doi.org/10.1177/1461444809105354

69. J. Patrick Williams and David Kirschner. 2012. Coordinated action in the massively multiplayer online game World of Warcraft. *Symbolic Interaction* 35, 3 (2012), 340–367.

70. Jason Wuertz, Scott Bateman, and Anthony Tang. 2017. Why Players Use Pings and Annotations in Dota 2. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1978–2018. DOI: http://dx.doi.org/10.1145/3025453.3025967

71. Nick Yee. 2006. Motivations for play in online games. *CyberPsychology & behavior* 9, 6 (2006), 772–775.

72. José P. Zagal, Jochen Rick, and Idris Hsi. 2006. Collaborative Games: Lessons Learned from Board Games. *Simul. Gaming* 37, 1 (March 2006), 24–40. DOI: http://dx.doi.org/10.1177/1046878105282279

LUDOGRAPHY

G1. Atari Games. 1985. *Gauntlet*. Game [Arcade]. (01 October 1985). Atari Games, Milpitas, California, USA.

G2. Blizzard Entertainment. 1998. *StarCraft*. Game [Windows]. (31 March 1998). Blizzard Entertainment, Irvine, CA, USA.

G3. Blizzard Entertainment. 2004. *World of Warcraft*. Game [OSX]. (23 November 2004). Blizzard Entertainment, Irvine, California, USA.

G4. Blizzard Entertainment. 2010. *StarCraft II: Wings of Liberty*. Game [Windows]. (27 July 2010). Blizzard Entertainment, Irvine, California, USA.

G5. Blizzard Entertainment. 2012. *Diablo III*. Game [OSX]. (15 May 2012). Blizzard Entertainment, Irvine, California, USA.

G6. Blizzard Entertainment. 2016. *Overwatch*. Game [Windows]. (24 May 2016). Blizzard Entertainment, Irvine, California, USA.

G7. Bluehole Studio. 2017. *PlayerUnknown's Battlegrounds*. Game [Windows]. (March 2017). Bluehole Studio, Seoul, South Korea.

G8. Bungie. 2010. *Halo: Reach*. Game [Xbox 360]. (14 September 2010). Microsoft Game Studios, Redmond, Washington, USA.

G9. Capcom. 2009. *Resident Evil 5*. Game [Windows]. (5 March 2009). Capcom, Osaka, Japan.

G10. EA DICE. 2013. *Battlefield 4*. Game [Windows]. (29 October 2013). Electronic Arts, Redwood City, California, USA.

G11. Electronic Arts. 2016. *FIFA 17*. Game [Xbox 360]. (27 September 2016). Electronic Arts, Redwood City, CA, USA.

G12. Gray Matter Interactive and Nerve Software. 2001. *Return to Castle Wolfenstein*. Game [Windows]. (19 November 2001). Activision, Santa Monica, California, USA.

G13. Hi-Rez Studios. 2012. *Tribes: Ascend*. Game [Windows]. (12 April 2012). Hi-Rez Studios, Alpharetta, Georgia, USA.

G14. Infinity Ward. 2009. *Call of Duty: Modern Warfare 2*. Game [Windows]. (10 November 2009). Activision, Santa Monica, California, USA.

G15. Piranha Games. 2013. *MechWarrior Online*. Game [Windows]. (17 September 2013). Piranha Games, Vancouver, British Columbia, Canada.

G16. Pocketwatch Games. 2013. *Monaco: What's Yours Is Mine*. Game [Windows]. (24 April 2013). Pocketwatch Games, San Diego, CA, USA.

G17. Riot Games. 2009. *League of Legends*. Game [Windows]. (27 October 2009). Riot Games, Los Angeles, California, USA.

G18. Treyarch. 2015. *Call of Duty: Black Ops III*. Game [Windows]. (6 November 2015). Activision, Santa Monica, California, USA.

G19. Ubisoft Montreal. 2015. *Tom Clancy's Rainbow Six Siege*. Game [Windows]. (1 December 2015). Ubisoft, Paris, France.

G20. Valve Corporation. 2007. *Team Fortress 2*. Game [Xbox 360]. (10 October 2007). Valve Corporation, Bellevue, Washington, USA.

G21. Valve Corporation. 2009. *Left 4 Dead 2*. Game [Windows]. (17 November 2009). Valve Corporation, Bellevue, Washington, USA.

G22. Valve Corporation. 2011. *Portal 2*. Game [OSX]. (19 April 2011). Valve Corporation, Bellevue, Washington, USA.

G23. Valve Corporation. 2013. *Dota 2*. Game [Windows]. (9 July 2013). Valve Corporation, Bellevue, Washington, USA.

G24. Wild Shadow Studios. 2011. *Realm of the Mad God*. Game [PC]. (20 June 2011). Wild Shadow Studios, Los Altos, CA, USA.