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Beyond Entertainment: An Investigation of Externalization Design in Video Games

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Abstract

This article investigates when and how video games enable players to create externalizations in a diverse sample of 388 video games. We follow a grounded-theory approach, extracting externalizations from video games to explore design ideas and relate them to practices in visualization. Video games often engage players in problem-solving activities, like solving a murder mystery or optimizing a strategy, requiring players to interpret heterogeneous data—much like tasks in the visualization domain. In many cases, externalizations can help reduce a user's mental load by making tangible what otherwise only lives in their head, acting as external storage or a visual playground. Over five coding phases, we created a hierarchy of 277 tags to describe the video games in our collection, from which we extracted 169 externalizations. We characterize these externalizations along nine dimensions like mental load, visual encodings, and motivations, resulting in 13 categories divided into four clusters: quick access, storage, sensemaking, and communication. We formulate considerations to guide future work, looking at tasks and challenges, naming potentials for inspiration, and discussing which topics could advance the state of externalization.

CCS Concepts

• ***Human-centered computing*** → ***Visualization;*** *Visualization theory, concepts and paradigms;* • ***Applied computing*** → *Computer games;*

1. Introduction

Video games as a medium have seen a steady increase in players in the last decades. With the advent of computing technology, video games have changed how they look and how players can interact with them. While text adventures from the 1970s, such as *Cave Story*, only allowed players to input actions in text format, modern video games use direct manipulation and visual feedback in detailed, interactive environments. Being an interactive medium that often includes problem-solving activities, video games can also allow players to externalize during gameplay. Expressing fleeting thoughts, making connections between points of interest, or simply recording information for some future purpose can make it easier for players to solve the problems they are confronted with. In visualization research, externalization has been a topic of interest in provenance [RESC16], annotations [CBY10, EG04], and sketching [Den05, LLY*23], though many systems still lack such functionalities. For which usage scenarios externalization features are best employed and which encodings and interactions make for good designs are questions under exploration. Because of their technical connections with visualization, video games present an opportunity to explore this design space from a different perspective. In this article, we analyzed a total of 388 video games to extract externalizations, following a structured approach inspired by grounded theory [CBF19]. Using this data, we provide a classification of all identified externalizations into 13 categories like hotbars and knowledge maps. These categories are further grouped into four high-level clusters: *quick access* (), *storage* (), *sensemaking* (), and *communication* (). For each category, we give detailed examples of discovered externalizations and connect them to related topics in visualization. Based on the collected externalizations and the characteristics of their associated games, we give design considerations for future work on externalization in visualization. The main contributions of this article are:

- A definition of externalization derived in a data-driven approach.
- An in-depth analysis of different externalizations extracted from a large collection of video games.
- Design considerations to guide future research for externalization in visualization.
- An annotated dataset that includes:
  - 388 **video games**, spanning release years from 1991 to 2024
  - 277 **tags** arranged in a hierarchy that describes different aspects of video games
  - 13.8k **tag assignments** by three different coders
  - 4.8k pieces of supporting **evidence**
  - 169 **externalizations** identified within video games

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2. Background

This section discusses relevant works on externalization in visualization and the relationship between visualization and video games.

2.1. Externalization in Visualization

Externalization is, not yet, a well-defined term in the visualization community. Likely originating from cognitive science and connected to theories like distributed cognition, it is linked to the interplay of internal and external representations [LNS08, ZS10]. In 2009, Chen et al. [CEH*09] discussed the relationship between data, information, and knowledge in visualization. They see data as computerized representations, information as meanings about data, and knowledge as results of simulated cognitive processes or human-acquired knowledge. In this framework, externalization could be seen as part of either interactions to control parameters of the visualization system or input into a computer-based knowledge system. At a similar time, Shrinivasan and van Wijk [Sv08] looked at "knowledge externalization" in the sense of supporting "[...] information synthesis for analytical reasoning." Related works employed annotations [Den05, EG04, ZGB*17], discussion forums [HVW07], and more complex systems that allow analysts to create *concepts* or note hypotheses [GWL*10, NXW*16]. Chen et al. [CBY10] presented the CLICK2ANNOTATE approach to support insight externalization in a semi-automated fashion. By insight externalization, they refer to "[...] the process of capturing and recording the semantics of insights in decision-making and problem-solving." More recently, Kim et al. [KHL*19] characterized analysts' externalization behaviors and defined externalization as "[...] offloading one's thoughts to an external medium [...]," which may encompass more than the externalization of *knowledge*. Federico et al. [FWR*17] define a conceptual model of knowledge-assisted visual analytics that describes how different types of knowledge feed into visual analytics environments. Their model includes externalization in the form of *knowledge externalization* and formalizes the potential benefits of using knowledge in visual analytics systems. Liu et al. [LNS08] and Hollan et al. [HHK00] look at visualization and human-computer interaction through the lens of distributed cognition. They emphasize the role interaction plays in coordinating between internal and external structures that together form a cognitive system.

All of these definitions include terms that are hard to pin down, such as *knowledge*, *insight*, *thoughts*, and *decision-making*. Which definition researchers use can heavily influence the kinds of systems they develop. CLICK2ANNOTATE [CBY10] makes use of predefined and analyst-created templates that record different types of facts about the data, like outliers or correlations. In contrast, VOGAYERINK [KHL*19] and ACTIVE(TH)INK [RHH*19] allow free-form annotations using a digital pen. These annotations are less structured than those created in CLICK2ANNOTATE. Still, they can be created faster and record different types of information without requiring a specific structure. Some works try to bridge the divide between manual labor and automation using mixed approaches to document chart findings in computational notebooks [LLY*23] or create annotation graphs [ZGB*17]. Although many systems have different foci and modalities, a coherent design space and guidelines are still lacking.

2.2. Visualization and Video Games

Both visualization and video games can be highly interactive systems in which users perform problem-solving activities. Interaction is key in both fields, because players and analysts must solve a problem or achieve a specific goal. To that end, data is communicated through visual interfaces that include text, widgets, as well as 2D and 3D visualizations. For a video game, its designers envision a particular player experience, often centered around entertainment. Some video games have a clear conception of how they should be played. In contrast, others include various gameplay features that allow for many play-styles, resulting in different experiences. Because the main goal is often not to solve a specific problem in the most efficient way possible, video games may include design decisions that create "unnecessary" challenges that could be solved more easily with more information or better tools.

Much research that intersects with video games explores how to visualize data *from* or *about* video games. For the latter, Wallner et al. [WK13] give an overview of gameplay data analysis using visualization. In another work, Kriglstein et al. [KWP14] visualize gameplay using heatmaps, among others, and compare their efficacy in a study with 29 players. Kleinman et al. [KPT*21] created a taxonomy for interactive visualizations for spatio-temporal game data. At the intersection of several disciplines, Adar and Lee-Robins [ALR22] framed a project for information visualization education through the language of video games. Video games often involve storytelling, which Zhao and Elmqvist [PSZ*22] include in their analysis of media types for data-driven storytelling.

Visualizations in video games exist but are not well-studied in their entirety, though some works investigated how visualizations are used in video games to communicate information to players. Zammitto [Zam08] provides an early view of visualization in video games, which was extended by Bowman et al. [BEJK12] to give an in-depth view of the video game design space and patterns. Other related works have analyzed game data [PTCM15], compared video games to real-world heads-up-display designs [TMZ*21], or looked at visualization in virtual reality (VR) games [RdSN18]. WISUALIZATION [BBRE24] is a unique work that uses video games as inspiration for the design of an extended reality visualization authoring tool. It takes magic and spells as a metaphor for interaction and gives users a spellbook that acts as a learning tool and history, enabling users to save unique interactions as spells.

3. Methods

We investigated a diverse collection of 388 video games to understand how they enable externalization during gameplay. To ground our discoveries in data, we followed a grounded theory approach [CBF19] with three coders collecting and analyzing data over five coding stages. A comprehensive analysis of our video game collection in terms of genres, release years, and user ratings can be found in the supplemental material.

3.1. Challenges and Data Collection

In contrast to investigating scientific literature, collecting and analyzing video games poses unique challenges. While scientific articles have standardized keywords and can be searched via text, the

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same is not possible for video games. Although genres and crowd-sourced tags exist, these may not be reliable or specific enough to find video games with desired features. Aside from simply finding relevant video games, analyzing them is equally time-consuming because the features of a video game might be distributed over the entirety of its playtime. In addition to playing the video games in question, reviews and video footage of gameplay can serve as another source of information. However, finding the right resource and thoroughly inspecting it is still time-consuming. To keep the workload manageable, we sourced data in the following way:

1. Include video games that coders played.
2. Include unplayed video games from the coders' digital libraries or wish lists.
3. Include known or popular video games that increase the data variety regarding release year or genre.
4. Include video games from curated lists. This includes online articles, videos, or blogs, for example, that discuss video games with particular game mechanics or ideas.

3.2. Coding Procedure

This section briefly describes the high-level results for the different coding stages. To collect and organize data, we used a web-based system [BWB25] that allows each coder to add video games, tag games, provide associated evidence, and define externalizations. Tags have the primary purpose of describing games and are organized as a hierarchy. Each tag has exactly one parent and only leaf tags can be assigned to a game. We explicitly differentiate between *tags* and *tag assignments*: The former are elements in the tag hierarchy, whereas the latter constitute a 3-tuple formed by a video game, the assigned tag, and the coder who made the assignment. As a result, each coder can create individual tag assignments. In this way, overlaps between tag assignments of different coders serve as a confirmation, whereas differences can indicate disagreement. Furthermore, evidence can be associated with tag assignments of a game to provide proof through descriptive text or images. In contrast to tag assignments, evidence is shared and visible to all coders to avoid unnecessary duplication. The externalization layer is built on top of these concepts: Each externalization is associated with one video game, describes how it presents itself within the game, and points to a subset of the game's tag assignments and evidence.

In total, we conducted five coding stages: an initial stage, two axial stages, and two polishing stages. During the initial coding stage, video games were added and tagged loosely to provide a first baseline of data that the next stages could iterate on. In the first axial coding stage, tags were refined and organized into a hierarchy for the first time. The second axial coding stage included adding more video games to increase data diversity, creating more tags to cover a larger number of video game features, and formalizing externalizations in the system. For the last coding stages, the tag hierarchy was refined, more evidence was added, and inter-coder agreement for tag assignments was improved. Whenever transitioning from one coding stage to another, all coders collaboratively assessed the current tag hierarchy, tag assignments, and potential shortcomings these assignments exposed. Externalizations were created by individual coders but discussed collaboratively until consensus among all coders was reached.

4. Coding Results

This section presents the coding results, starting with a description of the developed video game tag hierarchy and how we defined externalization. Then, we discuss the externalizations we extracted during the coding process.

4.1. Video Game Tag Hierarchy

Before explaining externalizations in video games in their different forms, we give a short overview of the tag hierarchy that describes the games in our collection. Due to its size, we cannot discuss the hierarchy exhaustively, but we briefly highlight relevant nodes and observations. On the top level, the tag hierarchy is divided into four subtrees: *form*, *content & substance*, *meta-mechanics*, and *problem-solving*. The first subtree contains tags related to the mechanics and structure of a game, describing the systems players interact with and the order in which game content is presented. In contrast, the second subtree captures game contents in terms of topics and settings, which is challenging due to the vast space of possibilities. In *meta-mechanics*, we collected high-level game features like the existence of tutorials or educational content. The last subtree describes the type of activities players perform to solve game-given problems and which personal challenges games may pose to the player. The latter was purposefully termed *personal* because different players engage with a game differently and might also bring widely different skill-sets with them. Some of the most common tags for all games concern the use of violence to progress and the inclusion of bars for visualization. While games do not generally include complex visualizations, many still need to communicate information to the player. This often takes the shape of a single-sensor-single-indicator philosophy [Goo81], in which each data source has its own dedicated simple visualization. The most iconic of these simple visualizations is probably the *health bar*, visualizing a player's health status based on some underlying numeric value, something familiar even to many non-gamers. Both the *form* and *problem-solving* subtrees play the most relevant parts for externalizations. Many externalizations are based around either specific mechanics or high-level strategies players use to overcome game challenges. A complete description of the tag hierarchy, games with their tag assignments, and externalizations can be found in the supplemental material at `https://osf.io/fhgm6/`.

4.2. Defining Externalization

As already touched upon in Section 2, there is no single concrete definition for externalization in the context of visualization and interactive systems. In the context of visual interactive systems, there are visual representations of data that are *external* to the viewer, that produce and interact with *internal* representations in the viewer's mind. Taking the distributed cognition view [HHK00, LNS08], these form a cognitive system that can uncover new information through interaction. In knowledge-assisted visual analytics [FWR*17, RWA19], knowledge is the internal entity that is transformed through interaction into a structured digital entity, which can be used to create new visual representations that feed the analysis process. Other more free-form approaches like ACTIVE(TH)INK [RHH*19] allow for any type of internal entity to be externalized through pen-interactions that create paths to

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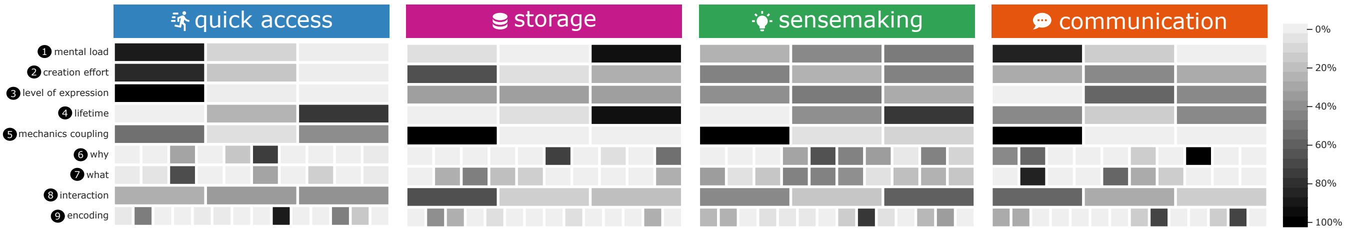

Figure 1: *Heatmaps that visualize relative occurrences for all values in the nine different dimensions (rows) that describe externalizations in video games for the four clusters from left to right: quick access (), storage (), sensemaking (), and communication ().*

meta		
	1 **mental load**	low - medium - high
	2 **creation effort**	low - medium - high
	3 **level of expression**	low - medium - high
	4 **lifetime**	transient - action-based - persistent
	5 **mechanics coupling**	uncoupled - coupled to optional - coupled to mandatory
	6 **why**	call-to-action - fun - location guidance - other - overview quick access - relate - share data - simulate - uncertain relevance
	7 **what**	category - descriptive information - functional reference - hypotheses intent - location - numerical values - relation - time - visual reference
how		
	8 **interaction**	free - object-related - enact
	9 **encoding**	color - game object - image - length - none - opacity - orientation other - position - shape - size - symbol/icon - text - texture

Figure 2: *All available externalization dimensions and their possible values, using the same numbering and ordering as in Figure 1.*

Figure 3: *The hotbar in the game* Stardew Valley*, developed by Eric Barone. It has 12 slots that can hold any item from the inventory for quick access via hotkeys.*

which users can assign different meanings. These meanings can be machine-readable (e.g., if users want a path to function as a selection) or they can be mostly human-readable (e.g., if users want to simply make a note). Combining these approaches, externalizations seem to be interactions that create (meaningful) digital representations of users' internal representation which feed into the system to act on existing entities. Such a broad definition makes externalization more of a synonym for interactions that affect external representations. To avoid this overly general view that turns everything into an externalization, we tried to create a practical set of requirements from this definition that can be used to identify externalizations, culminating in three pillars of externalization:

P_1 The user must provide data input to the system.
P_2 The externalization must have a lifetime that extends beyond its initial interaction.
P_3 The externalization must aim to reduce mental load.

Pillar **P_1** captures the connection between internal and external through interaction. The second pillar **P_2** excludes small, on-demand convenience functions that do not persist inside the system. With pillar **P_3**, we aim to capture what is meaningful about externalization; why users are externalizing.

4.3. Dimensions of Externalization

We defined nine dimensions to understand design differences between externalizations. These dimensions describe the following aspects, from top to bottom in Figure 1: the **mental load** of the related task, how much **effort** goes into creating the externalization, its **level of expression**, its **lifetime** in the game, its **coupling** to other game mechanics, **why** it is created, **what** is being externalized, how users **interact** to create it, and how the externalization is **encoded** visually. Figure 2 details the possible values for each dimension and the supplemental material gives an explanation for all of them. Analyzing similarities and differences between externalizations along these dimensions, we identified 13 categories that we divided into four clusters: *quick access* (), *storage* (), *sensemaking* (), and *communication* (). This section describes these externalizations in detail, examining different design aspects. In Table 1, we provide an overview of these categories and their relationship to mental load.

4.4. Categories of Externalizations in Video Games

This section gives a detailed breakdown of the types of externalizations by cluster and category, discussing their relationship to mental load and parallels to visualization research. Additional details like patterns we found using our web application [BWB25] can be found in the supplemental material.

4.4.1. Quick Access

The largest cluster in our collection of externalizations is the *quick access* cluster with 106 items, amounting to roughly 62% of all externalizations. Tags for games in this cluster are similar to the complete dataset, likely due to the cluster's large size. Here, we find externalizations that serve to give players quick access to information or specific functionality, often through customization.

Hotbars. A common functionality in games is some variation of a customizable hotbar. Hotbars have a limited number of slots to which players can assign items or abilities, giving them quick access to the resources they deem most relevant. The customizability of these slots allows the player to adjust their choice to changing circumstances. Figure 3 depicts an example for the game *Stardew Valley*, which gives players 12 slots to customize, each one accessible through a different hotkey. This hotbar is constantly displayed at the bottom of the screen, showing players their current selection

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Table 1: *This table describes all externalization categories through their related cluster, size, and relationship to mental load. Mental load is considered in terms of the load source, the amount of load, how it is reduced, how much effort the creation of externalizations is, and how additional load may be introduced. Mental load and creation effort can be low = ▫, medium = ▪, or high = ■.*

Cluster	Category	Category Size	Mental Load Source	Mental Load Amount	Reduction Mechanism	Creation Effort	Added Load
	hotbars	61	data space search time pressure	low	abstraction visual representation	low	learn abstraction
	organizable inventory	29	data space search	low	abstraction	medium	maintenance learn abstraction
	location guidance	12	mental transformation	low	visual representation	low	
	organizable windows	4	data space search	low	abstraction	medium	maintenance learn abstraction
	templates	7	data space size mental transformations	high	external storage	low	data space search
	screenshots	4	data space size	high	external storage	low	data space search
	notes	4	data space size	high	external storage	high	data space search disconnect
	knowledge maps	11	data space size data relationships	high	external storage annotation	high	maintenance
	placeholders	9	mental transformation data relationships	medium, high	visual representation	low, medium, high	maintenance
	labeling	11	data space size data relationships	medium, high	annotation external storage	low, medium, high	learn label space
	command queues	10	data space size time pressure	low, medium, high	workload compression	low, medium, high	
	pings	2	time pressure	low	abstraction	low	learn abstraction
	free expression	5	-	low, medium, high	-	medium, high	

of items and providing a quick way to use them. The hotbar category also includes other variants that are functionally similar, but visualized in ways other than showing a literal bar with slots—like radial quick access menus. A smaller subgroup of externalizations in the hotbars category are customizable control groups. Control groups are a different form of quick access, giving players access to selections of controllable units instead of items or skills.

Mental Load: Hotbars largely address low amounts of mental load that originate from a data space search. These types of quick access mechanisms are faster and more convenient, allowing players to learn a simpler abstraction (i.e., *where* something can be found).

Parallels: Similar functionalities can be found in the form of toolbars, like those in authoring systems [LTW*18, RLB19], pen-based systems [KHL*19, RHH*19], or software like Adobe Photoshop and Blender. In visualization, these toolbars do not usually include any customization, having more in common with a pre-defined hotbar. Other variations can be seen in provenance features, which contain a dedicated space that constantly displays user-created snapshots [CBB23, HMSA08, KRH17, NXW*16] or a history of interactions [BBRE24, GCL24, GLG*16, ZRB*21].

Organizable Inventory. In tandem with hotbars, many games give players an organizable inventory. Inventories in games are places to store items, usually available from a dedicated menu. In this category, inventories are largely grid-based, giving players the option to make item positions in the inventory meaningful and giving them a better overview of its contents. Organizing the inventory is usually a feature that requires constant maintenance as old items are sold and new items are found.

Mental Load: Inventory organization can reduce mental load by reducing a player's resources that are spent on searching through the data space, that is, the items. The amount of load that can be reduced with such a feature depends both on the number of items that are available and the size of the inventory.

Parallels: Organizing information spatially is somewhat similar to customization available in dashboards [FT16] or large-scale displays [AEN10], though the **organizable windows** category from this cluster (see below) makes for a more appropriate comparison. Explicitly organizing collected entities like data points is a rare functionality to find in visual analytics systems.

Location Guidance. Features for location guidance are ubiquitous in open-world games. Especially when games have a large world which players travel around repeatedly, game designers make navigation easier to prevent player frustration. Most commonly, this takes the form of location markers, generated automatically by the game for important locations, or set by the player manually. We only included location guidance based on player input (i. e., those directly placed by the player or enabled indirectly), because automated guidance violates pillar $\mathbf{P}_1$. While the choice of location is manual, the related display functionalities are always automated. For example, in the game *Outer Wilds*, players are shown a small arrow indicator at the edge of their screen. It lets the player know where the marked target is, relative to their current position, and displays the direct distance to their target as text.

Mental Load: Location guidance primarily relieves players of having to find the correct way themselves, thereby avoiding mental transformations from a map to the environment.

Parallels: Spatial navigation is not a task commonly associated with visualization, but some connections with research in user guidance can be found. Alrøe et al. [AHS24] used haptic force-feedback to guide users' cursor towards a specific data point and Han and Schulz [HS20] employ vibrotacticle cues for guided selection and navigation. While haptic feedback comes with distinct advantages and disadvantages, spatial guidance can generally be helpful when users are exploring a vast space [MSDK12] or working with large-scale displays [AEN10, AN12, AN13].

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Organizable Windows. Some games use movable windows to communicate information and enable in-game actions. When these windows are used often, customization can make working with them a little faster or more pleasant.
Mental Load: Similarly to the **hotbar** category, these externalizations let players learn easy abstractions that remove the need to discriminate windows based on other factors like appearance.
Parallels: As noted for the category **organizable inventory** (see above), organizing components can be found in dashboard applications [FT16]. The highest benefits for layout customization can likely be found in systems that target many users or those that users spend a lot of time in, for example, systems build for experts working on a specific domain task.

4.4.2. Storage

The storage cluster contains 15 externalizations that are created purely to store data for later reference. Though anything that persists for some time can be seen as being *stored*, these instances have the primary purpose to make something available for future look up. Games in this cluster exhibit a comparatively higher frequency of *personal challenges* that concern memory and discovery.

Templates. Some games allow players to create templates they can reuse. For most of these games, templates refer to a specific assortment of game objects that are built during gameplay and might be complex or time-consuming to construct. For example, players in *Besiege* build vaguely medieval siege machines to accomplish various goals across multiple levels. These machines can become rather complex, so the game lets players save them in templates for later reuse. Another type of template is found in *Pillars of Eternity*, in which players command a party of multiple characters. The game provides several formations that characters follow when moving through the world, but players can also define their own formation by arranging character portraits on a grid.
Mental Load: Templates, like other categories in this cluster, mainly address the mental load that comes with large or complex data spaces. Consequently, mental load tends to be high, but depends on the specific data space.
Parallels: For visualization, templates are employed as part of a structured analysis workflow [CBY10] or in authoring tools, for example, to animate volume visualizations [ACKL10] or to create visualization templates from sketches [OTC25]. Because templates can also be seen as a form of quick access, they similarly present an opportunity for users to define workflows or action sequences they want to perform repeatedly.

Screenshots. For games in this category, players are given a virtual camera to take photographs of their environment while playing. When a photograph is taken, it is usually stored in a gallery ordered by time. Games with such mechanics emphasize discovery; players primarily explore an environment that is littered with information in the form of documents, maps, items, and more. The player cannot take this information with them (e. g., in an inventory) and they often encounter it before they know its role in the bigger picture. A screenshot feature allows players to choose which environmental information to store for later look up.
Mental Load: Because these mechanics rarely provide ways to organize the stored information, they usually trade the arguably larger mental load of remembering all items in the data space with the load of having to search through the smaller, player-curated data space.
Parallels: Some visualization systems let users save a visualization [NXW*16, SSSEA20] or even a complete system snapshot that can be revisited later on [Sv08]. Especially when it is unclear which information is relevant at which point in time, having a rich history or data collection can make exploration tasks more manageable. A disadvantage of such a feature is that it can also result in additional mental load because users need to organize and search through their collection manually. Depending on the scale of available information, this can quickly become tedious.

Notes. Another storage category includes free-form text notes. These exist most often in games in which the main challenge includes understanding the relationship between different pieces of information, which players uncover over the duration of the game.
Mental Load: Note-taking can generally assist complex tasks by acting as external storage that can be referenced on demand, reducing load on working- and long-term memory. Note-taking is itself a complex task that introduces mental load in different ways [POK05]. Users need to comprehend information, identify relevant pieces, and construct a text-representation of that information [JLI17]. While it is certainly more convenient to have notes inside a system than outside of it, having no additional functionalities that connect the notes with the remaining system introduces additional mental load, making it time-consuming to use the created notes effectively.
Parallels: Visualization can itself be a tool to make note-taking more effective, explored in-depth by Willet et al. [WGI15]. For example, notes in VoyagerInk [KHL*19] are linked to visualizations both automatically and manually, which the authors highlight as a key feature to make externalizations useful in practice.

4.4.3. Sensemaking

The sensemaking cluster consists of 41 externalizations, making up around 24% of the total. These externalizations are used to solve problems the game presents by allowing players to record and organize information. Games in this cluster are more frequently tagged with tags about *organizing information* and *resource management* while having fewer tags related to skill challenges and violence.

Knowledge Maps. A few games in our collection give players the ability to explicitly map their knowledge. This comes in three distinct variants, but in all cases players can add or organize information to make sense *with*, often addressing mental load that stems from having a large data space to overview and understand relationships within. The first variant is the closest in appearance and function to actual knowledge maps [CCH*05], with players collecting, arranging, and connecting pieces of information on a board. *Shadows of Doubt* is an example in which players have a highly functional evidence board (cf. Figure 4). Not only can players organize information spatially, each piece of evidence is a functional representation from which players can explore connected evidence and initiate actions like calling a phone number, looking up personal details, or plotting a route to a location. Information can be collected from different sources—a printed email, a work id, or an address book—but it always automatically updates all related

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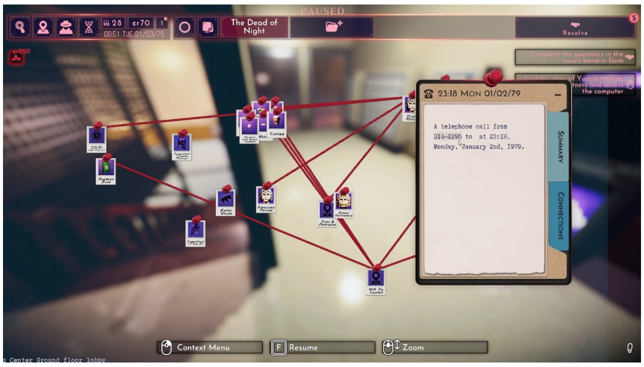

Figure 4: *An evidence board in the game* Shadows of Doubt *developed by ColePowered Games. Players can freely pin information as evidence and make connections between them.*

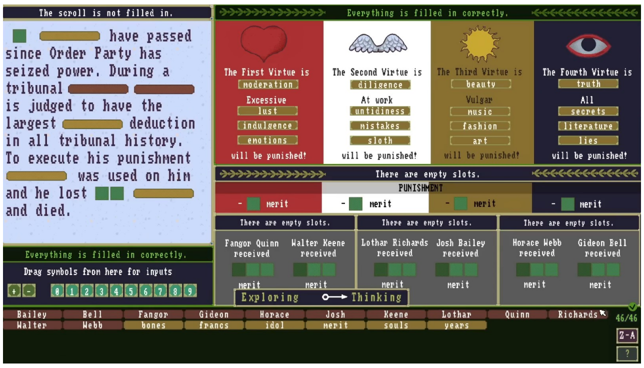

Figure 5: *A screenshot from the game* The Case of the Golden Idol *developed by Color Gray Games. Players have to assign collected entities to the correct slots for multiple panels.*

nodes, making information gathering a less tedious task. For the second variant, we found games in which players fill in gaps by assigning pieces of information to different slots. In *The Case of the Golden Idol*, players first explore one or more scenes to collect information in the form of small text blocks. These can represent a person, object, activity, location, or a number. Each level of the game then asks the player to fill in multiple blank spots using their collected entities, which grow in complexity over the course of the game (cf. Figure 5). Here, organizing information is a mandatory action players have to perform, but it simultaneously serves as a visual anchor for players to reason about their progress and hypotheses so far. A unique game mechanic in this category comes from the game *Etrian Odyssey*, which makes players manually annotate their world map. On a discrete grid, players can color individual cells and place icons to symbolize gates or items. The last variant includes two games with drawing overlays for sketching. Here, players draw on top of images or views that visualize parts of the problem, like a set of numbers or a collection of objects.

Mental Load: This category largely allows players to both simulate and visually represent a thought process in the game itself. The amount of mental load this can reduce is quite high, but it often comes at the cost of a high creation effort, which can be mitigated through clever interactions and automation.

Parallels: Externalizations from the first variant closely resemble concepts from knowledge mapping like mind maps [Lim14], somewhat akin to an (infinite) canvas some visualization systems provide for users to manipulate [RHH*19]. Study results showed that people still kept separate notes to track hypotheses, indicating a need for more integration to make cross-referencing easier. With Annotation Graphs, Zhao et al. [ZGB*17] provided a more functional representation, in which annotations are displayed in a graph with a mixed-initiative layout. Users can adjust the layout and perform meaningful actions on the nodes, like merging or pinning, making the organization of knowledge more efficient and tailored towards each individual user. For the gap filling variant, similar features are scarcely found in visualization systems, which may be due to clear task formulation that they require. However, these kinds of designs can serve as a form of self-explanation or help users learn how a visualization works. Self-explanation refers to the process of explaining something to oneself and can enhance learning and understanding of knowledge [CdLCL94]. Usually, self-explanations are driven by external prompts (e. g., by an educator), but computer-generated prompting may be promising for some scenarios [BLN*18]. A *fill-in-the-gaps* feature could be used to induce self-explanation, for example, when broad tasks are known or by letting users construct the gaps themselves. With KnowledgeVis, Coscia and Endert [CE24] used such an approach to let users interpret large language models. While not directly related to externalization, it shows how this design structures the process of exploring and comparing model predictions with a framing that works well for *people*.

Placeholders. In this category, we find externalizations in which players directly create and manipulate visual representations to support or replace mental simulation. For examples, games with a focus on building and management allow players to plan their building arrangement before actually committing to the decision. In *Prison Architect*, there is a blueprint mode that overlays a transparent blueprint consisting of walls and floor tiles over the normal game view. Because the game has several simulation systems with many knobs to turn, planning a layout beforehand can prevent frustration and reworks later on. Besides blueprints, there are a few games with logic challenges in which players can visualize competing possibilities. In *Minesweeper* red flags can be placed to signal bomb locations and in *Hexologic* players can assign sets of numbers to different cells that must follow specific rules.

Mental Load: Overall, externalizations in this cluster tend to address tasks with medium to high levels of mental load that derive from mental transformations combined with a large data space or dependencies between data points. Placeholders share many similarities with **knowledge maps**, save for a lower creation effort.

Parallels: In visualization, some annotation interfaces allow analysts to sketch on top of visualizations [Den05, KHL*19, RHH*19], similar to sketching overlays in this category. While planning is not a common task in visualizations, on-demand overlays could be used in other ways to provide benefits. For example, they might improve usability by spatially connecting externalizations and system data at the location of interest without cluttering the view or provide

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ways to combine automatically tracked interactions with externalizations that reference this data.

Labeling. Externalizations for labeling give players the means to tag specific game objects, for example, plants in *Strange Horticulture* or video clips in *Her Story*. What specific function they can serve depends highly on the implementation of the labeling system. In *Strange Horticulture*, players are tasked with identifying plants. They can add a colored label to any plant and include a short text, like a suspected name. Players have a shelf where they can see all their plants and hovering over a plant's label gives a larger view of the label. Taken together, these characteristics make this labeling system one that serves to group plants but also enables quick access and getting an overview. The labeling system in *Her Story* provides a different toolkit. Players must investigate the story of a murder and are given access to a database of police interrogation videos on a fictional desktop. They can search the database for specific video clips (based on the video transcript) but are only given a maximum of five results. Consequently, players must be clever about their choice of search terms. Video clips can be labeled with arbitrarily long text, allowing players to bring new variables into the search because it considers both the transcript and labels of a video. Because the number of accessible videos is limited in this manner, grouping and comparing videos to each other or quickly accessing them is much harder. Here, the labeling system acts more as an entity-based notebook that lets players store information they extracted from the clip that is likely not part of the transcript.
Mental Load: Due to the high variation in labeling systems, the mental load they address and cause is hard to quantify on a general level. It depends on the expressivity of the labels and how easily they can be modified.
Parallels: Some visualizations include labels or tags as part of an annotation system, which itself comes in one of two types: high structure with high functionality, but more required input and restricted freedom or high freedom with fewer automated features for retrieval and modification, making analysis of the annotations more laborious. ANNOTATION GRAPHS [ZGB*17] is a work more akin to the first type, in which users can create short word tags that show up as tag nodes in the annotation graph, connecting tags to all the functionality that comes with the graph itself. In other works that include annotations, free-form text is available, but not used to search or group annotations [HVW07, LLY*23].

Command Queues. For a small subset of games, we found queues that players can use to externalize. A command queue enables a player to plan a sequence of actions that will be processed automatically. These types of queues are common in real-time strategy games in which players control units that need to move through the game world, like *DotA 2* or *StarCraft II*. When movement is queued, this is often visualized by drawing a path with the specified waypoints on top of the game world.
Mental Load: Command queues can be seen as a type of automation, allowing players to compress their own workload to a shorter time span. The tasks themselves tend to be ones with low mental load, but under time pressure and in a large task space, load can increase quickly.
Parallels: Command queues have no direct parallels in visualization, because there are rarely tasks that must be performed in a limited time frame. However, they could be incorporated for systems with progressive visualizations [UAF*24], in which systems work on tasks for a longer time. Command queues could also be employed like a To-Do list: The user fills the queue at some starting point, removes tasks or questions that were completed, and adds tasks that need doing. While such an adaption misses the automated processing of the queue, it could still serve as a simple means to structure and monitor lengthy analysis sessions.

4.4.4. Communication

In the communication cluster, we find those externalizations whose primary function is to enable communication. The question whether communication serves to reduce mental load is something we found hard to answer, but viewing the group of players as a single system that must distribute information, mental load can arise in the form of inefficient communication that must be compensated through additional awareness and labor. The communication cluster is the smallest of the four, with only 7 externalizations and 4 distinct games. Because of pillar $\mathbf{P}_2$, voice communication is not counted as an externalization, as its data no longer exists after the initial utterance—though it is a common way for players to communicate in multiplayer games.

Free Expressions. This category includes externalizations with a high freedom of expression, like text chats in multiplayer games. Text chats with free-form text are extremely versatile, allowing players to banter, share information, or give commands. However, they come with the added load of having to formulate text, often under time pressure. As a response, players use abbreviations (e. g., in *DotA 2*, players used to write `oom` to indicate that they are out of mana). Another function a **text chat** can perform is to act as storage, either because it has a history or by letting players copy text from the chat into their computer's clipboard—where it will wait patiently until needed again. A unique way to externalize can be found in the game *Minecraft*, which lets players freely place blocks in a block-based world. Due to this large degree of freedom, placing blocks in the world can take on various meanings. Blocks can be placed as a form of building blueprint, they can acts as markers to indicate dangerous pathways, or text can be build *with* blocks—there are no limits to their creative application.
Mental Load: High levels of expression allow players to represent complex information, but often produce additional mental load because the creation effort is high as well. When timing is critical, it can be mentally taxing to formulate and type coherent sentences.
Parallels: Externalizing with a high degree of freedom comes with the advantage that complex information can be more easily represented, but it trades this for structure and machine-readability. Vi-

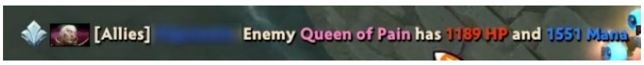

Figure 6: *A ping in the game* DotA 2*, developed and published by Valve. A player pinged the health bar of an enemy hero, which displays this message in the chat for all team members (the user name is blurred for anonymity).*

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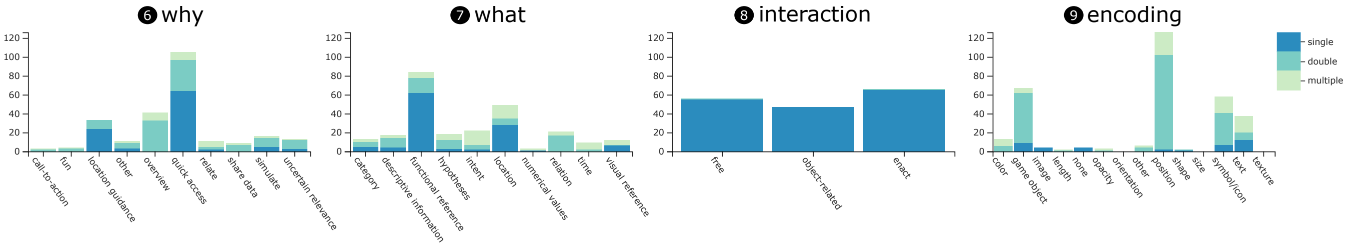

Figure 7: *Stacked bar charts showing the numbers of occurrences for the following externalization dimensions: why (6), what (7), interactions (8), and encoding (9). Because externalizations can have multiple associated values in a single dimension, bars are divided based on that cardinality: one value (**single**) in blue, two values (**double**) in light teal, and more than two values (**multiple**) in light green.*

sualization systems that support collaboration often include some form of free-text via chats or comments [HVW07,MT14,ZRB*21].

Pings. Externalizations in the ping category provide a solution to the problems that text chats can face by providing faster ways of communicating specific information. In *DotA 2*, there is a radial context menu which players can use at any location in the world to initiate one of several predefined communication actions. For example, players can indicate that they are traveling to a location, which is shown to all their team members in multiple ways: as a short-lived icon on the minimap, as a message in the text chat, and with an icon and text at the target location. Another variant of pings only displays a message in the team chat, usually containing numbers related to an entity in the game (cf. Figure 6). These pings are context-sensitive and always initiated in the same way: players hold a specific hotkey and click on the target game entity.
Mental Load: Pings are specialized forms of communication that reduce mental load by letting players use shortcuts instead of having to think about how to express information.
Parallels: Communication is a key part of collaboration, though its demands change depending on time and space contexts [IES*11]. Real-time multiplayer games, in which pings can be found, are comparable to distributed synchronous collaboration usage scenarios for visualization. Customized ping interactions can enable analysts to share high-level information *about* their sensemaking process, for example, the type of information they uncovered or where its source is located in the system. Pings as we discussed them here are efficient because of two key factors: First, the shape of the information is always the same and therefore easy to parse. Second, pings are tightly integrated with other information systems, like the text chat and minimap. With similarly tight integration into other communication and knowledge components of a system, pings are another way to support social aspects of collaborative sensemaking.

4.5. Insights from Other Externalization Dimensions

Here, we briefly describe some of the insights from other dimensions of externalization not discussed in previous sections. Figure 7 illustrates the overall distributions of values for the dimensions *why* ⑥, *what* ⑦, *interaction* ⑧, and *encoding* ⑨. Bar colors indicate how many values from one dimension an externalization has, whether its a single one (blue), a pair (light teal), or more than two (light green). Looking at why ⑥ players externalize, *quick access* dominates the distribution, followed by *overview* and *location guidance* in second and third place. Values other than *quick access* and *location guidance* almost never occur alone, reflecting more complex underlying motivations. Considering what ⑦ is being externalized, *functional reference* and *location* take the top spots. The *sensemaking* () cluster exhibits the largest variety of values (cf. Figure 1), having at least one occurrence for each value.

For interaction ⑧, we differentiate three groups: *free*, *object-related*, and *enact*. Interactions are *enacted* when they are semantically connected to the externalization, like dragging game objects to the desired location in a hotbar. An *object-related* interaction is performed on a game object but not enacted, for example, when players click on a game item and press a key. All remaining interactions fall into the free category, like entering text via a keyboard. Overall, values for this category are evenly distributed but vary depending on the cluster. For *storage* () and *communication* (), most externalizations use *free* interactions, whereas the other two clusters have a more even distribution, with a small preference for *enacted* interactions (cf. Figure 1). These differences might be related to the speed requirements for the respective externalizations. Examining visual encodings ⑨, there is a strong preference for using *position*. The *storage* () cluster stands out by not having the same preference for *position* and using single encodings frequently, which other clusters do not. In the *communication* () cluster, there is a higher prevalence for text encodings—likely because of their expressiveness—whereas game object renderings can be found across all clusters. These findings indicate that games rarely let players employ complex encodings, maybe because specifying them would be too tedious. In contrast, specifying a location is easy to do and understand.

5. Discussion

In our investigation of video games, we identified four clusters from 13 categories of externalizations, differentiated along nine dimensions. Our results show that players externalize for many reasons that find several parallels in visualization. In this section, we reflect on high-level insights from this investigation, proposing two design considerations (**DC**) and two research considerations (**RC**) to guide future work on externalization for visualization.

DC1: Start with tasks and mental load as guiding factors. Mental load is one of the nine dimensions we used to characterize exter-

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nalizations and is a relevant factor in differentiating the four clusters, which map to different high-level tasks. We suggest that designers begin their exploration of externalization by focusing on these aspects. Our findings indicate that externalizations in video games go beyond knowledge representation, suggesting that even simple tasks could benefit from their application. At the start, designers should consider the duration and frequency of tasks users engage in. For short high-frequency tasks, the *quick access* and *communication* clusters provide ideas for customization and communication for collaborative visualization [IES*11]. Hotbars can serve as storage that increases user awareness and gives quick access to chosen system entities. When working with large or complex data spaces, externalizations from the *storage* and *sensemaking* clusters show how to help users navigate and understand these spaces, for example, through labeling and knowledge maps. When reasoning about complex relationships, externalizations that offload mental simulation can prove helpful.

DC2: Closely analyze mental load trade-offs. In our collection, externalizations always include a trade-off in mental load, reducing one type of load but introducing another (cf. Table 1). For example, letting users take notes in the system reduces the load on memory, but introduces new tasks like finding and editing existing notes. Depending on the specific implementation, more mental load is thereby added to the process. Designers need to consider how their externalizations create mental load, making sure that added load does not outweigh the benefits. How much added load is tolerable depends on the amount of reduced mental load, but can also vary based on user preferences. Designers should consider *when* users want to externalize in their workflow and *when* they need to access externalizations. Tight integration with other system components that shortens interaction chains may also help in reducing added workload.

RC1: Find mitigation strategies to reduce added workload. Building on the previous design consideration, research should explore ways to reduce the mental load additional tasks impose, which may keep users from engaging with externalization features. The mental load trade-off is a significant challenge for externalizations, especially when both the reduced and added load are high, like in the *storage* and *sensemaking* clusters (cf. Table 1). Video games naturally engage players through intrinsic motivation, encouraging interaction with game mechanics despite increased workload. In contrast, visualization can lack intrinsic user motivation, requiring effective mitigation strategies to balance added effort with functional benefits. Because externalizations represent users' unique ideas and thoughts, users are the ones who often have to do the majority of labor associated with externalization. Designers should leverage automation, machine learning, and interaction design to ease this burden. Determining the most effective use of these tools in different contexts remains an open research question.

RC2: Understand and adapt to user needs. We propose that externalizations should help users *interact with* and *think about* entities, be they objects in a game or data points in a visualization. This makes them heavily user-centric—what works well for one user might not suit another. It is unlikely that one externalization fits every type of user, so having multiple options might serve different users better. However, an abundance of choices may introduce complexity that overwhelms rather than assists users in their work. Systems should therefore adapt to individual user needs, providing externalization features as required rather than presenting all options upfront. In a note-taking scenario, some users might prefer structuring data through tags, while others favor longer notes that reference data points. Ideally, a system supports both forms of externalization, but does not constantly push both of them on every user. This requires more work on user-modeling and user-adaptive visualization [YCON24] that lets designers offer the right type of externalization to each user. Our work provides a step towards mapping tasks and challenges to externalization types that can inform strategies for adaption.

5.1. Limitations

By necessity, our collection of video games is not representative of video games as a whole. There may be other types of externalizations in video games not included in our analysis. In contrast to scientific articles, video games can develop past their release, making statements about them obsolete. Features and mechanics in games can easily be missed, so the video games we analyzed may yet contain more features than we found. Another limitation relates to our derived definition for externalizations. The requirement pillars for externalization are at the broader end of the spectrum of possible definitions—they may refer to any kind of internal representation, allowing for any type of data input from the user. We arrived at this definition through multiple iterations of analyzing game mechanics and externalizations, considering where lines can meaningfully be drawn. This made our definition practical for this context, but it may not work as well for other contexts. Finally, although we identified many parallels between games and visualization, transferring insights from one to the other can be challenging.

6. Conclusion

In an investigation of 388 video games, we extracted and analyzed 169 externalizations to get an understanding of how they are designed, in which contexts they are used, and how these relate to different aspects in visualization research. Using a grounded-theory approach, we iteratively build hierarchies to describe video games and the externalizations they enable. Our inquiry uncovered 13 categories of externalizations distributed over four clusters, each defined by a different core task it supports. For all externalizations, we discussed the relationship to mental load, how they are connected to related topics and existing works in visualization, and how future research can incorporate our findings for the design of externalizations. Some externalization categories are based on well-known methods for knowledge mapping and can be found in both video games and visualization alike. In contrast, categories from the *quick access* and *communications* clusters may inspire future designs for novel externalizations or improved coordination in collaborative visualization. To help designers and researchers, we provide considerations pertaining to the design process and challenges for externalization. We hope that our dip into the externalization design space can act as a starting point for future research to build interactive visual systems that support users in externalizing effectively based on and with visualization.

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