



The Ludii Games Database: A Resource for Computational and Cultural Research on Traditional Board Games

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Abstract

As commercial tabletop and video games become increasingly popular throughout the world, traditional board games are becoming a form of endangered intangible cultural heritage, and in many places what were once widely played games have largely been abandoned. The Digital Ludeme Project applies artificial intelligence and computational techniques to the incompletely documented rules of traditional board games from 3500 BCE until the present to help preserve accurate knowledge of these games. The project engages with the historiography of knowledge about traditional games, determining which parts of the rules are provided by various textual, archaeological, artistic, and ethnographic sources. To document this knowledge and situate it geographically and chronologically, the Ludii Games Database provides the first comprehensive and rigorous Open Access database of scholarship on the global history of board games. Furthermore, the database is used as a source for data for the Ludii general game system, which makes the games playable and provides the analytical tools that will be used in future reconstruction work. Finally, the database may also serve as a reference tool for scholars pursuing research on games-related topics.

1. The Need for A Database of Games

1.1 Introduction

Games are a type of cultural heritage that have not been a particular focus of study in archaeology, anthropology, and history. Despite this, there is a hunger for information on games of the past, and books and websites about games have emerged in the public sphere which cover the topic. Even where this information is available, such research often does not accurately engage with the historical and archaeological record, since much games-related research is very old or not easily accessible. Furthermore, the recent explosion of game studies as a discipline of research in its own right, as well as the thirst for games knowledge among gaming communities and the interested public, demonstrate that there is an audience for research on games. Because of this, we developed the Ludii Games Database to document the preserved knowledge of board games. The database functions as the basis for the Ludii general game system, which uses a human-readable programming language to digitally model these games to make them playable. Importantly, this software facilitates research on games using AI-driven playout simulation. This paper discusses the need for a database of games and situates its construction around the task of modeling games digitally, while explaining how the Ludii games database solves many of these issues and provides a reliable knowledge base to seed future research on games in cultural and computational fields.

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1.2 State of Traditional Games Research

Such a task is not without challenges considering the history of games research. Though games have been a part of

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human life for at least the past 5500 years, the disciplines studying human society and its past (anthropology, archaeology, history, among others) have largely ignored games in favor of other areas of human life, such as power relations, economics, and religion. As a result, research on games is hindered by a lack of methodological and theoretical development that have characterized other topics of inquiry. There has been a reliance on certain key works (e.g., [Murray 1951], [Bell 1979]) that are outdated in their approaches, and the information they contain has proliferated in the Digital Age, leading to a situation where a large amount of information is readily available online but outdated, not referenced, or unreliable. The appetite for information and historical data on the games of the past is palpable, but historians, archaeologists, and anthropologists have not provided easy access to this information to the public, and so gamers and game enthusiasts have relied on old data and conclusions that are uninformed by theoretical and methodological advances. One salient example is the repeated assertion, from Henry Parker's *Ancient Ceylon* [Parker 1909], that incised patterns on the roof of the Mortuary Temple of Seti I at Qurna are evidence for the presence of games such as Mancala, Nine Men's Morris, and Alquerque in New Kingdom Egypt and thus dating to the middle of the second millennium BCE, despite the fact that they appear alongside graffiti with Christian iconography [Schädler 2021]!

In addition, starting in the twentieth century, the increased global market for proprietary tabletop and video games has changed the ways that people play around the world, and many traditional games have been lost since then [Komariah and Salim 2019], [Fabian 2023], [Appadurai 1995], [Mukherjee in press].

While early research on games largely used hyper-diffusionist paradigms to pinpoint origins and used imaginative reasoning to reconstruct the rules of games (e.g. [Murray 1951], [Tylor 1879]), over the last thirty years research on the games of the past has received considerable more theoretical and methodological rigour (see [de Voogt 1995], [Mackenzie and Finkel 2004], [Finkel 2007]). Moving past these topics, more attention was paid to board morphology, examining games as social processes [Crist et al. 2016a], and using quantitative methods to calculate similarities and classifications of games [de Voogt et al. 2013]. Now, with modern computational methods, it is possible to address some of the older research questions within a scientific framework. This was not possible before the advent of the techniques available to modern AI researchers, and provides not only another avenue for examining daily life in the past, but also the possibility to preserve this form of intangible cultural heritage [Crist and Soemers 2023].

All of these challenges and new opportunities present the need for a centralized, well-referenced database that records the known traditional games of human history, placing them within their geographic and chronological context, while clearly stating what rules are known to have been part of them. The Ludii Games Database [Digital Ludeme Project 2022] was created to document the knowledge of these traditional games, to serve as a resource for anyone interested in games, and to function as a knowledge base for proposing reconstructions of incompletely preserved games using AI. Defining games is, nevertheless, not always straightforward, especially when games are mechanically identical but geographically or chronologically distant. The Ludii Games Database takes a cultural and game-mechanical approach to defining games, which not only helps to highlight the different versions of similar games played by disparate cultures, but which also provides an analytical framework to examine the variability in games through time and space.

2. Digitally Modeling Traditional Games

2.1 Ludemes and the Ludii General Game System

The Digital Ludeme Project (<http://www.ludeme.eu>) investigates traditional games throughout human history to examine how human play has changed through time, and attempts to reconstruct playable rulesets using AI for those games for which complete rules have not been preserved [Browne et al. 2019], [Soemers et al. 2019]. Though the scope of traditional games is large, the project focuses on board games, which have been the most comprehensively documented form of traditional game for the last 5500 years of human history. The Ludii general game playing software [Piette et al. 2020], which was created for the project to be able to perform the necessary analyses for AI reconstruction, is able to accommodate analysis of other strategy-based games such as card and domino games as well. As of this writing, the project has documented 1058 board games for which enough information has been preserved to contribute to this research.

Games are modelled as structured sets of ludemes which represent fundamental elements of play. While different definitions of this term exist (e.g. [Parlett 2006], we understand ludemes to be any aspect of a game that is transferable between individuals and whose modification produces a functional change in play [Browne 2022]. This can include not only the rules of play, but also the equipment on which the game is played, in so far as its inherent geometry has a fundamental impact on the game. The following example shows the game Tic Tac Toe described in ludemic form in Ludii:

```
(game "Tic-Tac-Toe"
  (players 2)
  (equipment {
    (board (square 3))
    (piece "Disc" P1)
    (piece "Cross" P2)
  })
  (rules
    (play (move Add (to (sites Empty))))
    (end (if (is Line 3) (result Mover Win)))
  )
)
```

Ludemes, a term coined by Pierre Berloquin in 1970 [Browne et al. 2019], [Sorin 1970], can be thought of as game memes, even though their usage pre-dates the invention of the meme [Dawkins 1976], as both represent units of cultural information that are transmitted from person to person. And just as memes composed of multiple sub-memes are called memeplexes, we define ludemeplexes as compound structures of ludemes that combine fortuitously to provide a useful higher-level game concept. For example, the following ludemeplex describes the action of adding a piece to an empty site on the board, which is a concept used in many games and so convenient to wrap up into its own unit of game-related information:

```
(move Add (to (sites Empty)))
```

This approach to deconstructing games into their constituent ludemic elements makes it possible to digitally model the full range of traditional games required in a single consistent format. It exposes underlying correspondences between games that might otherwise not be obvious and allows the possibility of tracing fundamental concepts from game to game, throughout history, through the mechanisms of cultural transmission [de Voogt et al. 2013].

The language also uses specialized syntax to allow for the recording of missing rules in the implementation of games. Where it can be identified that rules are missing from our knowledge base, this can be indicated in the language.

This capability enables the automated identification and suggestion of potential rules to bridge these gaps [Crist et al in press]. Subsequently, the system can compile and playtest these games using AI-simulated play. Notably, Ludii features a variety of game-playing agents that not only enhance user interaction by allowing people to play against varied AI opponents but also facilitate AI research by providing diverse challenges and scenarios for testing and development.

The Digital Ludeme Project uses this ludemic approach to games, both in the compiling of the database and in the implementation of games in the Ludii software, which will utilize the data contained in the database to create playable digital versions of the games which have been fully documented. Ludii will also be the tool through which reconstructions of games will be achieved by testing possible rulesets and maximizing them for historical accuracy and playability metrics.

2.2 Preserving the Lost Knowledge of Traditional Games

Describing the ways that games change through time and the ways that new cultures adopt and alter the rules of play requires a conceptualization of games based on their means of transmission. The process of cultural transmission has been recently demonstrated as a valuable framework under which processes of change can be examined over large timescales [de Voogt et al. 2013]. The process of cultural transmission of games is dependent on the oral or experiential

mechanism by which people learn games. That is to say, that for the vast majority of human existence, games were, and still are, taught and learned by teaching another person the rules, either by explaining them or through playing together. This practice is largely the reason why the rules for most ancient and historical games are lost. They were rarely written down because people learned the games from others, and the vast majority of people who played could not write. Written rules did not become a major force for the cultural transmission of games until the Industrial Era, when games became a focus for commercial activity and were invented or appropriated for profit. Writing down rules creates a defined standard, fixed form of play that is refereed by a corporation, inventor, or governing body, which is drastically different from how games were more traditionally governed, which is by consensus of the players. The traditional form of transmission allows for changes to take hold through time and across cultures, creating different forms which are locally and, often, culturally bound.

Nevertheless, pieces of information that provide details about the rules of play for some of humanity's traditional games have survived in other media. Game equipment (boards, playing pieces, randomizers) have survived from antiquity, authors have discussed games and used rules of play as metaphors, artists have depicted games in their works, and ethnographers have documented games they observed or were taught, and, in rare occasions, historians and authors with particular interests in games have written treatises on game strategies and documented rules of games. In some cases, such as the ancient Egyptian game Senet, there are hundreds of references to the game and artifacts which survive (see [Piccione 1990]); others, such as Aksadyuta, are only known from one source (in this case, the Mahabharata, an Indian saga [Syed 2020]).

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The key to determining what is known about these games is to compile the preserved rules knowledge for each game to determine what is known and what is absent. Under the Digital Ludeme Project, for the purposes of game reconstruction and for the purposes of software implementation, games are conceived as a collection of ludemes. The artifacts, artistic representations, texts, and ethnographic accounts of game rules provide information about which ludemes were used in any given game. For the purposes of this project, any source which provides a ludeme or which places a game chronologically or geographically is referred to as evidence. The suite of evidence for a particular game provides an honest accounting of what is known about the rules of a particular game, and where and when that knowledge is situated in time and space (Figure 1). This allows for the identification of what knowledge is missing for the game to be playable, as well as allowing for comparison with games in similar times and places, which could suggest ludemes for reconstruction purposes.

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Figure 1. Figure 1. Board and pieces for the game of 58 Holes. These artifacts provide the board geometry and number of pieces per player for the game. From Asasif, Egypt, ca. 1814–1805 BCE. Metropolitan Museum of Art 26.7.1287a–k.

The game Ludus Latrunculorum provides an illustrative example of how rules can be identified from evidence. The game is known from Roman sources, and was played between the second century BCE until possibly the seventh century CE. Varro (*De Lingua Latina* 10.22) indicates that the game is played on a quadrangular board; Ovid (*Tristia* 2.477–478) states that a piece is captured when it is between two of the opponent's pieces, and pieces move along a straight path and can move backwards. The anonymous author of *Laus Pisonis* 192–193 states that the pieces are placed on an empty board to begin play, indicating the existence of a placement phase in the game (i.e. there is not a fixed starting position). Actual boards have been found in many parts of the Roman Imperium stretching from the Antonine Wall in Britain to Egypt's southern border, consisting of a rectangular board with of a grid between six and ten squares per side, the sides sometimes being equal but often, unequal — six-by-seven, six-by-eight, eight-by-eight, and eight-by-nine are some that are attested (see [Crist et al. 2024], [Schädler 1994]). The game also appears in art. A terracotta model of a Ludus Latrunculorum game from the Fayyum Oasis of Egypt depicts a six-by-seven board with seventeen pieces placed in the squares of the board [Petrie 1927], showing that the pieces were placed in the squares rather than on the corners (as is the case with some games), and that there were at least seventeen pieces in the game, assuming that the uneven number represented shows that some have been captured.

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Because of the state of game research, much of what is known about the games of the past is obscured by assumptions, misconceptions, and overly imaginative interpretations that have become repeated as fact, particularly in publicly-accessible resources. Thus, secondary texts are not very reliable when they report on the history and known rules for games. Indeed, sites such as BoardGameGeek and Wikipedia, which contain a great deal of information about

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games, typically rely on popular works with outdated methodological approaches and data such as *A History of Board Games Other than Chess* by H.J.R. Murray [Murray 1951], or those which do not consistently report the source of their information about games, such as R. C. Bell's *Board and Table Games of Many Civilizations* [Bell 1979]. For this purpose, a database of the games from humanity's past, connecting them to the evidence for what their rules are and placing them within their chronological and geographic context, is required to first be able to identify what is known and what needs to be reconstructed. This database not only functions as a data source for the Digital Ludeme Project, but also as an Open Access resource for anyone researching board games.

3 The Ludii Games Database

3.1 Conceptual Framework — Games

To identify connections between games and document their changes through time, defining boundaries between discrete games becomes a challenge. Although games are largely defined based on mechanical considerations, i.e., the rules of play; there is some question of when to determine that a game is different enough from another to consider it a separate game. Furthermore, there are many simple games which are identical in their rules, but which are separated in time and/or space to such a degree that cultural transmission seems to be an implausible explanation, and thus should not be considered the same game because they could have been independently invented or the product of convergent evolution. Therefore, the Ludii Games Database takes a hybrid cultural-functional approach to defining games. A game is considered different from another game if it has non-trivial rule differences from another game, or if two games are separated from one another chronologically or geographically in such a way that combining the history of the games as played in different places does not make sense.

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For example, the English game Backgammon and the Greek game Portes are nearly identical in their rules [Malaby 2003], and though they are very obviously connected to each other in some way, it does not make sense to connect the history of Backgammon in England with that in Greece, because the history of these places is subject to different cultural interconnections and nearby gaming cultures that could have contributed to changes in game play. Furthermore, Chess in medieval Europe is virtually identical to the game Shatranj as it was played in Southwest Asia at the same time, and undoubtedly Chess was derived from Shatranj itself [Murray 1913]. Though the rules are identical, Chess in Europe had a different history, with different social connotations and divergent future developments into the modern game, so these games are catalogued separately in the database.

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3.2 Rulesets

Games data in the database operates as a high-level, societal description of games. Rulesets, however, function as medium-level descriptions of how the games were played. Rulesets describe the specific equipment and rules of play associated with a game. They are considered differently from games because, for the purposes of game reconstruction, games may have multiple rulesets. For example, the game Alquerque, known from medieval Spain, was described differently by two different authors, Alfonso X [Golladay n.d.] and Covarrubias [1674]. The rules are compatible with each other, but Covarrubias describes capturing in greater detail than Alfonso X. Because it cannot be assumed that these capturing details were played in Alfonso's time, these rulesets are considered distinct for the purpose of analysing the game.

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In addition, many of the games of antiquity have been reconstructed by other scholars and game enthusiasts, and it will be useful to analyse their rulesets for historical accuracy and playability. Functionality allowing multiple rulesets per game makes this possible. In addition, during the process of game reconstruction, it will be necessary to consider multiple possible rulesets as potential reconstructions. It is likely that some games will have multiple plausible reconstructions, which will be considered as separate rulesets associated with one game, rather than as separate games unto themselves.

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Because rulesets serve these different roles, they are assigned to the following categories for analytical purposes:

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- Described rulesets are those which were written by someone who was part of a culture in which the game

was regularly played;

- Observed rulesets are those which are reported by someone from outside the culture playing the game, for example, in an ethnographic account;
- Scholarly rulesets are those which are proposed by an expert on that particular game or to the culture from which it belongs, such as rules for Senet as proposed by an Egyptologist;
- Suggested rulesets are those which were created by someone interested in or knowledgeable about games more generally, who has proposed rules for a game;
- Reconstructed rulesets are those which are identified through analysis in the Ludii software;
- Incomplete rulesets are those which are missing key portions of the rules which render them unplayable. Incomplete rulesets most often appear as compilations of the known rules for a game as presented by the evidence documented for that game, but they can also be rulesets described by an author that are known to be incomplete because they leave out an important piece of information that renders the game unplayable — such as starting position, winning condition, or other crucial game mechanism.

As already mentioned, games within Ludii are described using keywords known as ludemes. Multiple ludemes can also be combined together into ludemeplexes, which describe certain aspects of a game such as a piece of equipment, or a rule for how a player moves. In a similar manner, each ruleset is made up of many of these ludemeplexes. Due to similar mechanics being present across multiple games, many of our rulesets will share ludemeplexes, and many of these ludemeplexes will share ludemes. As such, the ludemes portion of the database records which ludemeplexes are associated with each ruleset, as well as the ludemes which are used in these ludemeplexes (and by extension the rulesets as well). Ludemeplexes can also be associated with specific mathematical keywords (e.g. addition, subtraction, rational numbers, etc.) and gameplay-based concepts (e.g. stochastic, hidden-information, asymmetric rules, etc.)

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3.3 Evidence

Finally, the portion of the database which is most crucial for historical reconstruction and cultural heritage preservation relates to the evidence. Evidence consists of primary sources of information that provide information about where, when, how, and by whom a game was played. Evidence is crucial to empirically document which ludemes can be included as part of particular games, which allows for the identification of candidate ludemes to fill in lacunae during the game reconstruction process. It also allows us to identify which cultures played certain games, and to position them in time and space.

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Because the game reconstruction process will also trace games geographically and chronologically, each piece of evidence must provide geographical or chronological information, which can be expressed either as a point/date or region/date range. This can be, for example: the date and findspot of an artifact, the date a manuscript was written and the place it was written (or describes), the place where a person observed a game and the dates they were there. This is the minimum amount of information required for a piece of evidence, which will only identify the presence of a game in a particular place and time. Evidence which provides information about game rules, such as board geometry, number of pieces, type of randomizer used, starting position of the pieces, capturing and movement rules, and so forth, are more important for determining the rules for games. Preference is given to collecting this kind of evidence in the database, where it is possible.

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In addition, certain information on the social context of these games is collected. Because the Digital Ludeme Project is interested in tracking the dispersal of ludemes through person-to-person contact, it must be recognized that games were sometimes restricted to people by social class, age, gender, and other social factors. Documenting these will allow us to account for situations where, for example, a game played by non-elite children in one culture is less likely to be connected to one played by elite adults in a neighboring culture than another game that was also played by elites or adults.

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The game, ruleset, and ludeme data is all supported and drawn from the evidence data (see Figure 2). Evidence can provide single ludemes, full or partial rulesets, or contextual, geographic, or chronological data that can be assigned to a game. Evidence need not inform all three categories of data, but must inform at least one of them.

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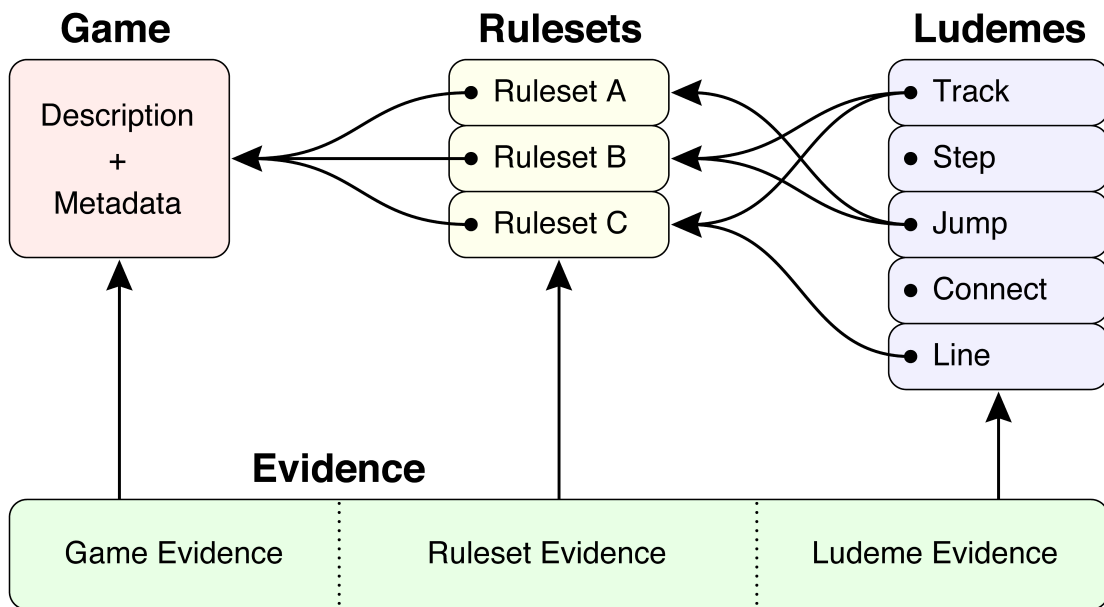


Figure 2. Figure 2. Conceptual diagram of the relationship between games, rulesets, ludemes, and evidence.

3.4 Database Format

The Ludii Games Database is stored as a MySQL-based database structure, made up of many linked tables. These tables can be split into the same four conceptual groups mentioned previously, Games, Rulesets, Ludemes, and Evidence. Each group contains a single “Fact” table, which lists all elements (games, rulesets, ludemes or evidence) of its corresponding conceptual group. Each group also contains multiple “Dimension” tables, which list different possible values for certain element properties (e.g. Periods, Regions, Categories), and “Junction” tables, which pair specific elements in the Fact tables with values in the Dimension tables.

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Figure 3 shows a complete Entity Relationship Diagram (ERD) of the Ludii Games Database. Each section is coloured based on its conceptual group: evidence in green, games in red, rulesets in yellow, and ludemes in blue. Please note that the three tables in the orange section belong to multiple sections. Blue coloured tables signify Fact tables, purple coloured tables signify Dimension tables, and pink coloured tables signify Junction tables.

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this section is not calculated by or drawn from that in any of the other database sections.

Specific entries within the Ludii Games Database can be individually accessed using its unique identifier. The unique identifier for an entry is represented in the form DLP.T.N, where T is the name of the table within the Ludii Games Database and N is the Id field value of the entry (e.g. DLP.Games.426 or DLP.Evidence.532). The field values associated with a unique identifier can be viewed using the link <https://ludii.games/identifier?Id=DLP.T.N> (e.g. <https://ludii.games/identifier?Id=DLP.Games.426>).

4. Presenting the Database

The information stored in the Ludii Games database is publicly accessible via the Ludii Portal (<https://www.ludii.games>). This website provides the front-end interface for downloading the complete database, but also for users to explore the database in a manner more accessible to them. The complete list of games can be found at <https://www.ludii.games/library>.

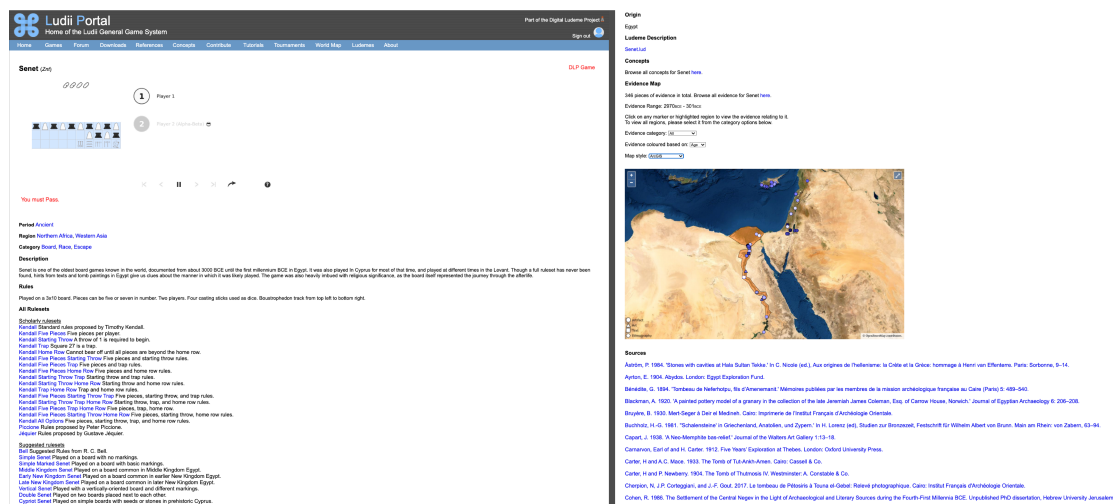


Figure 4. Figure 4. Game page for Senet, <https://ludii.games/details.php?keyword=Senet>.

4.1 Game Pages

Every game that is being investigated as part of the Digital Ludeme Project has a corresponding page dedicated to it (see Figure 4). The page collects the information relevant to that game and its associated rulesets from the database into a single page and presents it in a manner that is more user-friendly. Importantly, it also embeds a playable version of the Ludii-based implementation — when a playable ruleset has been identified. This stripped-down instantiation of Ludii allows a single player to play against an AI game-playing agent.

Relevant information, such as its rules, historical information, references, and an interactive map of any associated evidence are also included to inform the user about the game. References are linked either to the original document, when they are available in an Open Access digital format, or to their WorldCat entry. Information such as period and region are calculated from the chronological and geographical range for the evidence for that game, allowing users to search for games pertinent to their interests.

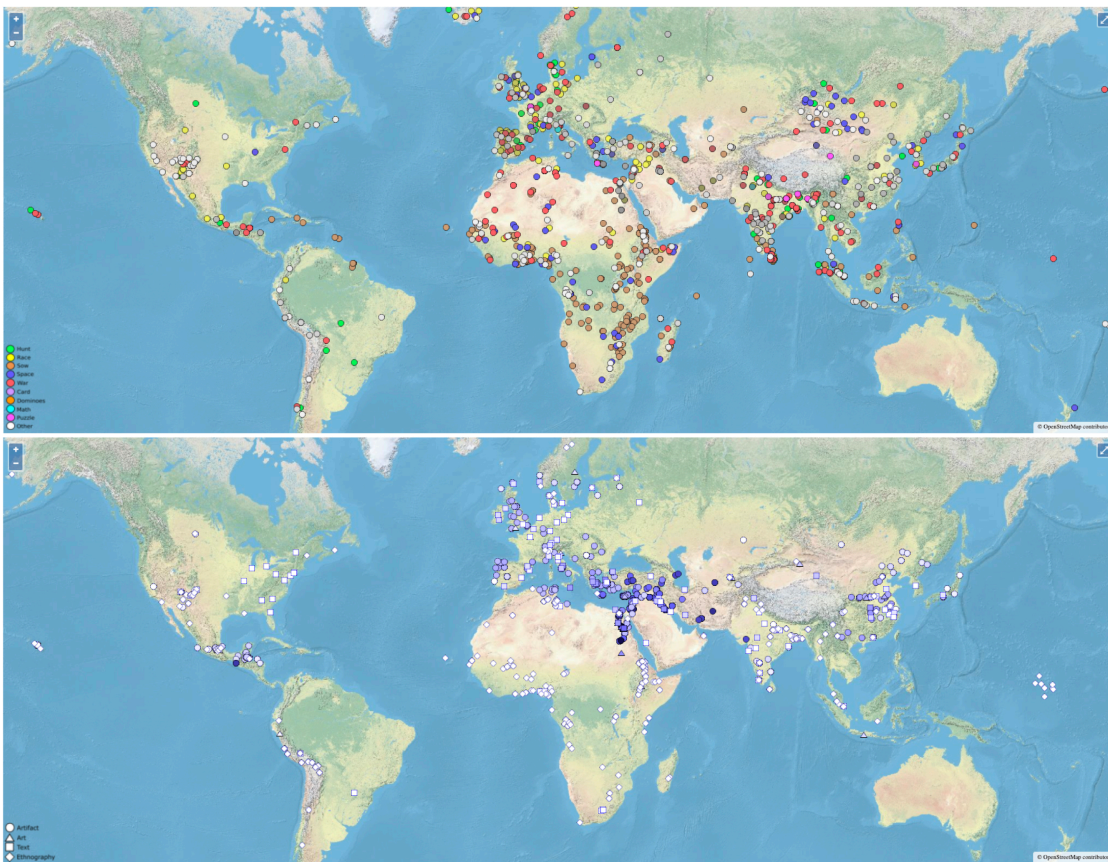


Figure 5. Figure 5. World maps from the Ludii Games Database. Top with the earliest piece of evidence for every game (<https://ludii.games/worldMap.php>), bottom with every piece of evidence with a specified location (<https://ludii.games/worldMapEvidence.php>).

4.2 World Maps

Two world maps (Figure 5) provide visualization of the evidence for games that have been compiled in the database. The first displays a complete visual representation of all games with evidence around the globe. Each identified game has a single point placed on this map, with its location based on the earliest known piece of evidence associated with it. The colour of each point is based on its game mechanisms category (e.g. Mancala, Race, Hunt), which is based on Parlett's classification [Parlett 1999]. The tone of each point is based on its age (darker represents earlier, whilst lighter represents later). Each point links to the relevant game page. The map includes a slider which allows users to define a beginning and end year to select a time period, causing the map to display the games that existed between those years.

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Another map provides a complete visual representation of all pieces of evidence around the globe. Each identified piece of evidence with a specific location has a single point placed on this map. The shape of each point is based on the kind of evidence it is (i.e. artifact, art, text, or ethnography). The tone of each point is based on its age (darker represents earlier, whilst lighter represents later). Clicking on a point displays the information about that particular piece of evidence.

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4.3 Forum

The Ludii Forum provides a message board interface for allowing users to communicate with members of the Digital Ludeme Project team, as well as each other. This forum is divided into several different categories (General, Questions, Suggestions, Problems, Competitions) where users can enquire about various different aspects of Ludii and the Digital Ludeme Project. Engagement with users is crucial for not only identifying software bugs, but also has the potential for engaging with users who are familiar with traditional games which are not published in the scholarly literature. The forum also provides announcements of any new updates or changes to Ludii, as well as information about upcoming events such as AI competitions or conferences. As of the time of writing, the Ludii Forum has over 800 registered users.

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4.4 Concepts

Concepts represent aspects of game mechanics and metrics that can be shared between different games [Piette et al. 2021]. Each concept is expressed in game-terms well-known by game players and designers. A concept can be associated with the game itself, a particular state that occurs during gameplay, or a move played. They can be related to the equipment of the game (board or pieces), to the rules of the game (game setup, ending conditions, or movement of the pieces), and to more general aspects such as various properties (e.g. symmetries, information type, time model). These data are particularly interesting to compare, analyse and evaluate games.

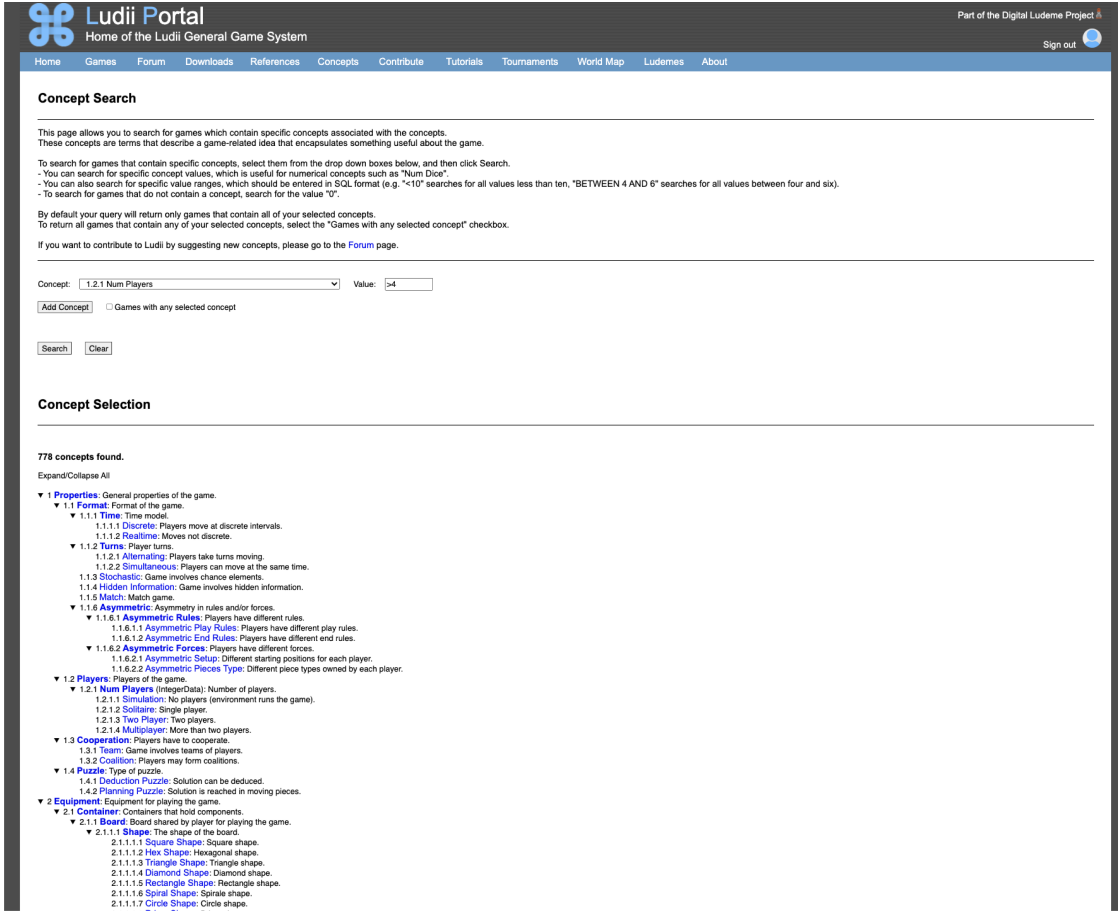


Figure 6. Figure 6. Concepts search page on the Ludii portal. The concept “1.2.1 Num Players” has been selected, along with the value “>4”.

The Concept Search page allows users to search for games that contain specific combinations of these concepts (see Figure 6). Instructions are provided at the top of the page, below which users can select specific concepts and associated values. In Figure 6, the concept “1.2.1 Num Players” has been selected, along with the value “>4”. Additional concepts can also be added as needed. Clicking the “Search” button will return all the games which satisfy this request, in this case, those which have more than four players. At the bottom of the page, a complete hierarchy of all concepts is also provided.

Within Ludii, AI agents are used to compute specific concept values, crucial for reconstructing games with enhanced historical accuracy and improved playability. Ludii represents gaps in game rules using symbols and compiles this information into structured data to pinpoint ludemes that can complete these rules. After identifying potential matches from its database, Ludii ranks these based on their cultural, geographical, and conceptual proximity [Stephenson et al. 2023] to the original game rules. This process enables Ludii to generate comprehensive rulesets, which are then filtered to align with established board game concepts and the evidence gathered for these games.

4.5 Data Management

The Ludii Games Database is archived at DataverseNL [DANS and Maastricht University 2022], an Open Access data archiving platform. It is managed by DANS [Royal Netherlands Academy of Arts, Sciences and Dutch Research Council 2022], the Dutch National Centre of Expertise and Repository for Research Data, and partner institutions including Maastricht University. New versions of the database are uploaded with each update of the Ludii software, and the version number of the database matches the version of Ludii associated to it. DataverseNL preserves the data for at least ten years after the last publication based on the dataset, after which time the data will be migrated to one of the archival platforms managed solely by DANS.

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5. From Data Collection to Research

5.1 Challenges and Opportunities in Data Collection

Because the Ludii Games Database was built specifically to support Ludii in achieving the Digital Ludeme Project's AI-based game reconstruction research, there have been challenges in translating game-related evidence from historical and archaeological data in ways that provide meaningful representations of what is known about a particular game. For example, as described above, we considered games where evidence documents identical complete rules in different cultures to be different games. This model is difficult to apply in the deep past, where evidence is both sparse and incomplete for games. One example is for the Egyptian game Senet, which was played for roughly three thousand years in Egypt, Nubia, West Asia, and Cyprus, at various points in time [Crist et al. 2016b]. For ancient games like this, we decided to use a different model where a given piece of evidence may provide only a portion of the rules. For example, a limited selection of evidence for Senet indicates the track along which the pieces move through the sequence of squares on the board. We want this evidence to be considered as part of the game everywhere it was found. Where there is evidence to suggest there may be variations in the way this game was played, such as boards that are marked with distinct patterns in the playing squares to presumably indicate certain gameplay events, these were separated into different rulesets for Senet, so they can be considered separately from one another, but still as part of the set of evidence that more broadly defines what we know about this game.

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The structure of the Ludii Games Database allows for flexibility in different kinds of game research, while also handling the complexity of defining boundaries between games. The relationships between entities in the database allow us to easily tie games, rulesets, and evidence to one another, but also provide flexibility in situations where we decide that ancient or historical evidence should actually be associated with separate games or rulesets, rather than one. For example, boards from the Roman Empire were originally connected to the English game Nine Men's Morris because they shared the same board, but it was later decided that the Roman material should be considered separately, and the existing evidence tied to the newly entered game "Roman Merels" instead. Such flexibility allows for easy changes that will occur as analysis of different games progresses, as the project anticipates identifying connections between different games that may indicate that two separate games should be considered the same, or that one should be separated into two different ones. This demonstrates the flexibility of the database, as entries can be changed as new evidence for games emerges, so games can be redefined and evidence reassigned.

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Other challenges present opportunities for creative solutions in the future. There are many boards, objects, and brief accounts that may indicate the existence of board games that are not easily defined into ludemes. For example, there are many finds throughout the ancient world of singular or small groups of dice or playing pieces, which cannot be defined as belonging to a particular game or as a meaningful ludeme. Because the Ludii Games Database is built to use evidence to define the ludemes that belong to a game, the documentation of these kinds of objects does not add knowledge about particular games. Nevertheless, game-related material in a particular place and time still points to the presence of a game there. Such is the case, for example, of a recently-discovered group of pieces from Başur Höyük, Turkey [Sağlamtimur 2017], which probably consist of several groups of pieces belonging to an unknown set of games.

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Some of the emerging conclusions from the ongoing data collection is that a considerable amount of documentation needs to be done to achieve the same level of resolution of games knowledge across the globe. Particular regions of the world are strongly represented in our database either because they are well-published in Western European languages, (such as India and Sri Lanka) or because a particular researcher took an interest in the games of a

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particular place and comprehensively documented them (such as in Mongolia [Kabzińska-Stawarz 1991] and the Horn of Africa [Pankhurst 1971]). Eastern Europe, as well as East and Southeast Asia, are areas which could particularly benefit from the collection of further data, as the information from games in these areas is either primarily published in local languages or not documented. South America is also a place which historically has received little attention from games research, and recent work in Argentina suggests there is a considerable amount of evidence for indigenous board games that remains undocumented [Ferrarese 2005].

5.2 AI-centered research

The existence of a database such as this one provides numerous unique research, pedagogical, and heritage preservation uses related to games. The Ludii software provides a powerful tool for AI-based research on games. In computer science, games have been a particular focus of research, as games provide simple, discrete, rule-based systems that can lead to the development of AI techniques [Crist and Soemers 2023]. However, because of the lack of cultural data on traditional games, AI research that attempts to use such games must rely on outdated, incompletely documented, or speculative sources. Having an academically-sourced database of games from which AI researchers can identify candidate games relevant to their research adds to the accuracy and relevance of their findings. This can also support applications of data mining and machine learning analysis, including automated game evaluation, portfolio/ensemble agent training, and personalised user recommendations. Furthermore, the Ludii software provides certain advantages that improves the accessibility of this research with its human-readable language.

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AI applications to games research can also help to augment our understanding of the (pre)history of games. AI-driven simulated play in Ludii offers opportunities for researchers to study games by allowing AI agents to play games and generate quantitative data that can help to answer research questions, but which would be prohibitively time consuming to generate through human play. For example, we conducted AI experiments to explore the archeological evidence for the Roman game Ludus Latrunculorum, mentioned above. Using the concepts search menu, we manually identified games (Kharebga [Bellin 1964] and Seega [Davies 1925], [Lane 1836]) that contained all of the rules known to have been used in this game, and simulated play to determine their playability on the wide range of sizes of rectangular or square boards found at Roman-era sites. This research determined that boards smaller than ten-by-ten squares are more likely to have been used for this game, and larger ones were probably another game not discussed in the Roman sources, probably one played by the indigenous population of Europe outside of Italy, since these boards were found largely away from the urban centres of the empire [Crist et al. 2024].

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Through the description process embedded in Ludii, we can pinpoint gaps where information on game rules is missing. Ludii then procedurally identifies potential playable rule sets that might fit these gaps [Crist et al in press]. Calculations based on game distance — i.e., the vector distance between two or more games using the shared concepts (rules, mechanics, design and strategies) they contain [Stephenson et al. 2023] — can be coupled with other distance measurements meant to model social change across time and space. This methodology allows Ludii to match a game with closely related ones, using their rules as a basis to propose new, quantitatively plausible rule reconstructions for historical games. Work on this process is ongoing. We are also exploring the application of AI-simulated play to attempt to identify play that replicates use-wear on archaeological game boards, another method that could potentially aid in the identification of rulesets [Crist et al. 2022].

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There is also the possibility of examining cross-cultural comparisons of the experience of play through the comparison of behaviour metrics generated through AI-simulated play. For example, comparison of the number of turns it generally takes to play a particular game could inform research on time as experienced during play. The identification of mathematical concepts, strategies, and techniques that exist in particular games can also be explored using this data [Piette et al. 2022]. Research on AI-simulated play as a proxy for the experience of human play is in its infancy, and we expect that further applications and research will only grow in coming years.

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5.3 Cultural Research

In addition to this, there are wide applications outside of AI research for the Ludii games database. As discussed above,

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game studies has over the past twenty years developed as a discipline largely focused on video games and driven by the commercial success and cultural prevalence of that industry [Mäyrä 2008], [Nieborg and Hermes 2008]. Despite the more than five thousand years of documented history of human game playing, research on historical, ancient, and traditional games has been embedded deep within the literature of the disciplines that research their time periods, in multiple different languages, and even still is quite rare. Thus, the kind of data necessary to produce high quality cross-cultural and/or diachronic research has been prohibitively difficult to access, especially when compared to video games which can be experienced as part of contemporary culture, are easily accessible, and provide more obvious lines of research because of their complexity and intersection with research on other forms of media.

The Ludii games database thus provides a centralized space for people to research traditional board games and to expand some of the phenomena examined in game studies as a more universal human experience. Any research must be grounded in documentation of the games and cultures of play that surround them, so facilitating connection to the sources that discuss the games in a given time and place is crucial to improving future research. Research questions that have been discussed in particular cultural contexts can then be explored in other cultures or even on a worldwide basis. For example, the impact of colonialism on games [Mukherjee in press], [Mukherjee 2022] can be discussed in a broader sense with better access to information on games in diverse cultural contexts. The database can also provide a resource for studying how traditional games change through time — an important process of cultural transmission that can help us to model how ideas travel and change that is not dependent on exchange of goods or materials [de Voogt et al. 2013]. Many of the games in the database were documented in the nineteenth and early twentieth century, but few people have reviewed whether these games are still played today. Are the rules different now? Do they vary from community to community? The evidence in the database can serve as a starting point from which scholars can gather new data on traditional games and then compare this data to what was gathered in another time and place to explore change through time, to examine cross-cultural contact or how cultural practices change within a particular society. Modeling how games changed through time and how different social processes affect rule changes could go a long way to creating models of cultural change more broadly. These applications discussed here are not comprehensive, but the opportunities presented by having accessible data are great.

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5.4 Future Development

The scope and content of the Ludii games database will continue to expand through the help of the COST Action GameTable: Computational Techniques for Tabletop Games Heritage. This initiative brings together scholars with research backgrounds spanning AI, cultural disciplines, mathematics and education to develop new ways to explore the ways these fields intersect to study intangible tabletop games heritage [Piette et al. 2024]. One of the main ways that this will expand the database will be to include traditional card and domino games in a similar format, as these are crucial forms of tabletop games that are not yet represented and are supported by the Ludii playing software [Morenville and Piette 2024]. We will also explore ways to mitigate the challenges indicated above, as well as to incorporate more visual material. GameTable will also explore developing more human-like AI algorithms, which will allow for AI-simulated play that more closely imitates human behaviour rather than optimal play, thus providing scholars with a better research tool for games research. It will also explore explainable search techniques for playing agents and reinforcement learning approaches to discover interpretable strategies for playing these games [Soemers et al. 2024].

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Though the Ludii Games Database serves as a depository for information about traditional games from around the world and is fundamentally designed to provide data to be used by other researchers. Even more importantly, it is accessible to the general public and non-specialists who are interested in traditional and historical games from all around the world, presenting data on games honestly and transparently. But most crucially, it provides a place online where information on traditional, historical, and ancient games, many of which are no longer maintained by traditional player communities, can be preserved and new communities could form around them, since they are playable in Ludii. Through partnerships with museums and cultural organizations, we are exploring strategies for further developing methods of preservation of gaming heritage. There is also a considerable opportunity for the use of the database as a pedagogical resource, not only to teach about game studies, but also in many relevant disciplines that could highlight games as cultural practices of historical importance. This comprehensive resource therefore contributes to the validation of game studies as useful to people studying other kinds of cultural phenomena, and provides a new strategy for the

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