# Virtual world, defined from a technological perspective and applied to video games, mixed reality, and the Metaverse

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**Abstract**

There is no generally accepted definition for a virtual world, with many complimentary terms and acronyms having emerged implying a virtual world. Advances in networking techniques such as host migration of instances, mobile ad hoc networking, and distributed computing, bring in to question whether architectures can actually support a virtual world. Without a concrete definition, controversy ensues and it is problematic to design an architecture for a virtual world. Several researchers provided a definition but aspects of each definition are still problematic and simply can not be applied to contemporary technologies. The approach of this article is to sample technologies using grounded theory and to obtain a definition for a "virtual world" that is directly applicable to technology. The obtained definition is compared with related work and used to classify advanced technologies such as a pseudo-persistent video game, a MANet, virtual and mixed reality, and the Metaverse. The results of this article include a break down of which properties set apart the various technologies; a definition that is validated by comparing it with other definitions; an ontology showing the relation of the different complimentary terms and acronyms; and the usage of pseudo-persistence to categories those technologies, which only mimic persistence.

**KEYWORDS**

definition, mixed reality, Metaverse, MANet, virtual world, video games

## 1 | INTRODUCTION

There is no generally accepted definition for a virtual world and Schroeder[1] highlights the need for a definition. There is controversy on the meaning of the term "virtual world" in various communities and research,[2,3] with many complimentary terms and acronyms emerging implying a virtual world, but which are qualified so as to specialize the concept, for example, massive multiplayer online role-playing game (MMORPG). Advances in networking, such as host migration of instances, mobile ad hoc networking, and distributed computing, bring into question whether architectures can actually support a virtual world. With concepts, such as virtual reality[4] and the Metaverse,[5] should these contemporary architectures be classified as virtual worlds or something else? When a virtual world is not well defined and without a concrete definition, designing an architecture specifically for a virtual world is problematic, for example, tactics often used in existing publications are refraining from providing a reference to the virtual environment used, naming properties that constitute the virtual environment relative to their publication, or only referring to examples of existing implementations.

Bell[6] has published a think piece to spur up discourse towards a definition. Bartle initially described properties of a virtual world in his book, Designing Virtual Worlds,[7] and later clarified each individual property. Researchers[8-10]

have attempted to provide a definition for a virtual world (e.g., through literature review), but aspects of each definition are still problematic. Current definitions simply can not be applied to contemporary technologies, allowing for the classification of technologies such as the online productivity tool, Google Docs[11]; the video game, League of Legends (LoL)[12]; the many shards of the virtual world, World of Warcraft (WoW)[13]; or the Internet as a whole. It does not buy us anything to refer to everything as a virtual world, even though it might be possible.

If a definition for a virtual world can be determined, it can be used as a base, which can then be qualified to more specific usages, for example, qualifying the definition for a networked virtual environment (net-VE)[14] with the "massive multiplayer" property to form a type of MMVE. Rather than obtain a definition for a virtual world through a literature review, the approach in this article is to use grounded theory.[15] Sample technologies are added to the study and analyzed for properties related to a virtual world; properties that are determinants of a virtual world together form the new definition. The analysis continues until the definition is no longer refined, but sampling simply confirms the theory. Twenty-six technology samples were analyzed including commonly used software, communication technologies, video games, web technologies, and early and contemporary virtual worlds. The properties found in Bell[6] and Girvan[9] provided a starting point for the study.

The resulting definition, obtained through grounded theory, is verified against prominent existing definitions. The effectiveness of the definition is demonstrated by creating an ontology of virtual worlds, in other words, clarifying acronyms related to virtual worlds, for example, VE, MUVE, MMVE, VI3DW, MMOW, MMORPG, or IVW. And a form of "discriminant sampling"[16] is used, that is, selecting advanced contemporary technologies that were not in the study to see if the theory holds true for these additional samples; classifying advanced technologies, such as a pseudo-persistent video game, a MANet, virtual reality, mixed reality, and the Metaverse.

Results of this article include a detailed definition for a virtual world, with detailed definitions of all underlying terms used. The definition is applied directly to technology for classification, showing which properties set apart the different technologies. Remaining properties that do not determine a virtual world are listed so that they can be used to distinguish between the various virtual worlds. The resulting definition is tied to the accepted definition of a net-VE, by Singhal and Zyda.[14] Distributed peer-to-peer, cloud-based, and MANet networking are taken into account so that they do not invalidate the definition. And the concept of pseudo persistence[17,18] is used to categorize technologies, which only mimic persistence.

## 2 | RELATED WORK

Many descriptions and definitions for a virtual world can be found in literature, but there is no consensus. Dionisio et al[5] state that "virtual worlds are persistent online computer-generated environments where multiple users in remote physical locations can interact in real time for the purposes of work or play," but the description assumes a virtual world accessed by a single player on a local computer, rather than from a remote location, fails to be a virtual world, even if the implementation is unchanged.

Bartle[19] updated his criteria with respect to his previous publication.[7] Unfortunately, the updated criteria only implies shared time and space and fails to capture the "worldliness" of a virtual world. Each property found in his definitions is added to the study below and his concepts of an avatar and persistence are adopted.

Bell and Robbins-Bell[8] obtain a definition through literature review, stating a virtual world to be "a synchronous, persistent network of people, represented as avatars, [and] facilitated by networked computers." Aspects of this gathered definition are not sound: Synchronous communication is mentioned, but the definition does not take into account if participants share time or space; similar to Dionisio et al,[5] a single player on a local environment fails to be in a virtual world; and the concept of agency is discussed with regard to avatars but is not captured in the definition. Bell and Robbins-Bell state that social networks like Facebook are not virtual worlds, because "a social networking site has persistence but no sense of synchronous environment (and therefore no sense of space)." In that statement, a synchronous environment is unclearly attributed to a sense of space. The underlying definition used, by Raph Koster,[2[#33]] stating that a virtual world is "a spatially based depiction of a persistent virtual environment, which can be experienced by numerous participants at once, who are represented within the space by avatars," is of interest; the properties of spatial depiction, persistence, and avatars are considered in the study below.

Similar to Bell and Robbins-Bell, Girvan[9]* has also gathered properties for a virtual world through literature review and compiled a definition for a virtual world, namely, "a persistent, simulated, and immersive environment facilitated by networked computers, providing multiple users with avatars and communication tools with which to act and interact in world and in real time." All properties are added in the study below.

Schroeder[1] argues for the definition of a virtual environment or virtual reality technology to be "a computer-generated display that allows or compels the user

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*Girvan was contacted in regard to this technical document; she noted that an article was in press concerning the same content but was not publicly available at the time of this writing.

(or users) to have a sense of being present in an environment other than the one they are actually in and to interact with that environment"; the "being there" is then translated to a multiuser collaborative shared virtual environment, where participants can interact. Although sufficiently vague to perhaps remain valid into the future, the definition can not be used to determine an architecture for a virtual world using, for example, instances, cloud computing, MANets, etc. Schroeder continues to differentiate virtual reality or virtual environments from virtual worlds on the basis that virtual worlds have been applied to persistent online social spaces. The definition by Schroeder does not discern if Facebook or the Internet at large is considered a virtual world. The properties of multiuser, sharing, interaction, and online are examined in the study below.

According to Spence,[10] a virtual world is a "persistent, synthetic, three-dimensional, nongame centric space," making a distinction between games and social spaces. No such distinction is made here, because (social) play can be considered part of gaming. Applying his definition, Spence was able to classify 37% of the surveyed projects as virtual worlds, leaving 50% to be classified somewhere on a continuum of hybrids. In addition, Spence considers the Metaverse a virtual world, whereas in this article, the Metaverse is considered to be similar to the Internet, in accordance with Dionisio, Burns III, and Gilbert.[5]

In literature, Singhal and Zyda[14] can often be found as an underlying reference with respect to a virtual world. Five common features are said to distinguish a net-VE: a shared senses of space, a shared sense of presence, a shared sense of time, a way to communicate, and a way to share[14[p.3]]. Unfortunately, the features are described too vague to be useful for classifying technologies, for example, a "shared sense of space" with respect to the instance dungeons of WoW or MANets, and a "shared sense of time" with respect to multiple possible abstractions of time. It is unclear why a "way to communicate" and a "way to share" are chosen as features rather than action and interaction. A graphics engine and display are mentioned as the cornerstones of a net-VE, and so properties related to these are added to the study.

## 3 | METHODOLOGY AND SCOPE

Rather than obtain a definition through literature review, grounded theory[15] (a systematic approach according to Creswell[16]) is used, that is, a definition can be formed from any possible criteria related to a virtual world, rather than being limited to definitions or criteria found in previous literature. Sample technologies were chosen and analyzed for properties related to a virtual world. Initial sources of sample technologies and properties were Girvan,[9] Bartle,[7] Bell and Robbins-Bell,[8] and Combs et al.[2] Additional properties were

sought, until the collection thereof correctly classified all the sample technologies. Theoretical sampling was used to select technologies that could pose a problem for the classification, until the point of "theoretical saturation" was reached; "at this point, new empirical data does not help the researchers to further develop the theory."[15[p.48]] Twenty-six technologies (see the Appendix) were sampled before theoretical saturation was reached. The most difficult properties to locate were those differentiating video games and virtual worlds, but thereafter sampling stopped because no other technology could be found in the consulted literature that was radically different enough to challenge the theory.

The novelty in using grounded theory to classify technologies that implement a virtual world is that if a new technology emerges it can be handled, that is, if the new technology challenges the current theory, properties can be added to the theory and the definition updated.

### 3.1 | Semantics

Before presenting the study, it is important to clear up the semantics surrounding the term virtual world. Perhaps one reason for the lack of definition is because of a language problem. The word "virtual" can be used to mean "being such in power, force, or effect though not actually or expressly such"[20]. This leads to an interpretation of, for example, a "virtual world of electronics," that is, there is almost an entire world of electronics or an imaginary world consisting entirely of only electronics. The meaning of "virtual" related to computers can be defined as "temporarily simulated or extended by computer software"[20], leading to usages such as a computer-generated visualization of the digital world of electronics or a simulation of a world. The word "temporarily" in the definition can be justified by the fact that it is nearly impossible to create a truly persistent world.[17] This article shall concentrate on the lattermost meaning of a virtual world, being a world simulated by computers, ruling out the imaginary. Note the distinction between an (imaginary) world created in the minds of users while using a computer system (e.g., perhaps while using a telephone) and a virtual environment that is simulated by a system, which then is perceived by users to be a world. In popular discourse, a virtual world is sometimes used to refer to the concept of an MMORPG, but an MMORPG is shown to be a higher level concept below. Also, in popular discourse, when dealing with "mixed reality,"[21] it is sometimes helpful to regard the system as "a virtual world overlaid on the physical world,"[22] that is, the world of the virtual overlaid on the physical; those components that are virtual, in contrast to physical. And lastly, according to Schroeder[1] "the word 'virtual' has come to mean anything online (as in virtual money)." Speaking of a "virtual transfer" could be problematic in the sense of it being sim-

ulated by a computer, that is, it did not really happen; ergo, calling it an "electronic transfer" sidesteps the problem. That "virtual money" is simulated is not a problem. Schroeder[1] notes an ambiguity in the usage of virtual money to mean money within a virtual world, which is a more specific type of simulated money. By definition, the term "online" means "with or through a computer, especially over a network"[20], implying virtual and networking. The property of being online is added to the study below.

According to Qvortrup[23][p.26], a "world" is "the all-encompassing context for the totality of human activities and experiences." Creating such a world might prove impossible. By creating a virtual world, an allegory of the physical world is modeled or simulated. Note, "world" is not equal to a planetary world, for example, the science fiction universe of EVE Online[24] is a virtual world, which consist of an abundance of planetary worlds. A difficulty in obtaining a definition, as shall be seen, lies in quantifying the world of a potential virtual world, that is, determining if the world qualifies as "worldly" enough. If a world is described as an environment that consists of people, places and things, sharing time and space, then respective properties can be added to the study, as a starting point.

## 3.2 | Virtual (simulated) environment

For the purposes of this article, a Virtual Environment (VE) is considered to be minimally one that is "wholly synthetic"[25], simulated by a computing device and supports the least spatial property of containment.[25] Milgram and Colquhoun[21] clarify that a VE is one "which must necessarily be completely modeled in order to be rendered"; contrary to the real (physical) environment over which "the computer does not possess, or does not attribute meaning to, any information about the content."

It should be noted that there are several abstractions of simulation possible within a computing device, for example, (in general) the micro instructions of the CPU simulate instructions of the CPU, which in turn simulate assembly or higher level languages, which in turn simulate the operating system of a computer, and which in turn can simulate the software engine simulating a VE. If a technology can provide for one or more (MANY) "data spaces,"[26] then the loaded state in MANY data spaces can possibly constitute a VE. It is possible to have MANY environments nested in other environments (e.g., multiple software running on the OS); a virtual world is a specialization of MANY VEs. This logic is counter to the initial choice of words by Bartle,[7] who found world more encompassing, because it is "not so easy to see how you could have several worlds within an environment"[2][#9] Of course, when Bartle was cocreating MUD,[7] EVE Online did not exist, that is, an abundance of planetary worlds. In his updated

definition, Bartle[19] specifies that a virtual world should be "automated," implementing a "set of rules (its physics)." The property of a virtual world being automated is captured here by referring to a simulation, where the simulated VE has its rules or physics.

## 3.3 | Architecture

If an architecture aims to support a virtual world, it must implement the various properties of a virtual world (e.g., persistence). Architectures are often chosen to satisfy additional requirements, for example, mobility, decentralization, or scalability. Restrictions on computing resources, such as memory, computation, and networking often determine how much of a virtual world can be loaded on a single client or server; some tactics for dividing up world space are discussed below in relation to ONE shard. Scalability is often a reason to choose a particular architecture that is related to size. Various communication architectures can be used to allow clients to connect to a virtual world (see Communication Architectures).

## 4 | GROUNDED THEORY

Each section below defines or clarifies a property that is used to classify sampled technologies (if possible) in the grounded theory; classification details can be found in the Appendix in an underlying section with the same section heading. Final results are recorded in Table 1. As a guide, abbreviations found in parenthesis of each section heading correspond to the column headers of Table 1, Table 2, and those found in the Appendix.

## 4.1 | Simulated (ST) / virtual temporality (VT)

Similar to the simulation of a VE, there are several layers of abstractions present when examining temporality in computers, for example, the internal hardware might run at a particular frequency (a number of cycles per second, Hertz); computer programs are perhaps triggered according to an internal clock; and the operating system might have another abstraction of time, that is, there can be an arbitrary number of abstractions of time.

If the internal clock frequency is referred to as hardware temporality, the abstraction of time that is simulated using hardware temporality can be referred to as ST; a computerized clock (usually at an accuracy of milli- or nanoseconds) that emulates "real-world"[27] time, but which can be altered independent of real-world time, since it is simulated. Computers systems often maintain ST as an "epoch"[28] plus a number of time units (an offset). Instrumenting real-world time incurs instrumentation error (i.e., ST is not exactly equal

**TABLE 1** Do the technologies support the properties of Shared Temporality (`1T`, MANY (+) shared real world (`R`), hardware (`H`), simulated (`S`), or virtual (`V`) time); Real time (`Rt`); Shared Spatiality (`1S`); ONE Shard (`1Sh`); MANY Software Agents (`SA`); Virtual Interaction (`Ix`); Nonpausable (`nZ`); Persistence (`P`, world persistence (`wP`) and/or data persistence (`dP`)); and an Avatar (`Av`)? Yes (✓), No (X), or an underlying requirement is lacking (-) (see the Appendix for details)

| TECHNOLOGY | 1T | | Rt | 1S | 1Sh | SA | Ix | nZ | P | | Av |
|---|---|---|---|---|---|---|---|---|---|---|---|
| email chess | - | ⊢RS | X | ✓ | ✓ | - | - | - | ✓ | ⊢wP∧dP | X |
| calculator | - | ⊢RH | ✓ | - | ✓ | - | - | ✓ | X | | X |
| CAD | ✓ | ⊢RHS[V] | ✓ | ✓ | ✓ | X | - | X | X | ⊢wP∨dP | X |
| Google Docs | - | ⊢RS | ✓ | - | ✓ | - | - | ✓ | ✓ | ⊢wP∧dP | ✓ |
| Skype incl. video | - | ⊢RS | ✓ | - | ✓ | - | - | ✓ | ✓ | ⊢wP∧dP | ✓ |
| IRC | - | ⊢R[S] | ✓ | - | X | - | - | ✓ | ✓ | ⊢wP∧dP | ✓ |
| Zork | - | ⊢RH[S] | ✓ | ✓ | ✓ | - | - | ✓ | X | ⊢wP∨dP | ✓ |
| Civ5 | ✓ | ⊢RS[HV] | X | ✓ | ✓ | ✓ | ✓ | - | X | ⊢wP∨dP | ✓ |
| Doom (Deathmatch) | ✓ | ⊢RHSV(RSV) | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | ⊢wP∨dP | ✓ |
| League of Legends | ✓ | ⊢RSV | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ⊢pseudo-wP∧dP | ✓ |
| MUD | ✓ | ⊢R[H]SV | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ⊢wP∧dP | ✓ |
| WoW, ONE shard | ✓ | ⊢RSV | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ⊢wP∧dP | ✓ |
| WoW, all shards | X | ⊢RS[V+] | ✓ | - | X | ✓ | - | ✓ | ✓ | ⊢wP∧dP | ✓ |
| Facebook | - | ⊢RS | ✓ | - | ✓ | - | - | ✓ | ✓ | ⊢wP∧dP | ✓ |
| the Internet | X | ⊢R[SV+] | X | - | X | ✓ | - | - | ✓ | ⊢wP∧dP | ✓ |

**TABLE 2** The logical ∧ of all properties (values in brackets next to a property, means those properties fail due to lacking an underlying requirement; the properties Virtual Temporality (`VT`) and Virtual Spatiality (`VS`) can be found in the Appendix, see Table A.2 A1 and Table A.4 A2 respectively)

| TECHNOLOGY | ∀p:∧ | |
|---|---|---|
| email chess | X | ⊢VT[1T,SA,Ix]∧Rt[nZ]∧Av |
| calculator | X | ⊢VT[1T,SA,Ix]∧VS[1S]∧ P∧Av |
| CAD | X | ⊢SA[Ix]∧nZ∧ P∧Av |
| Google Docs | X | ⊢VT[1T,SA,Ix]∧VS[1S] |
| Skype incl. video | X | ⊢VT[1T,SA,Ix]∧VS[1S] |
| IRC | X | ⊢VT[1T,SA,Ix]∧VS[1S]∧1Sh |
| Zork | X | ⊢VT[1T,SA,Ix]∧P |
| Civ5 | X | ⊢Rt[nZ]∧P |
| Doom (Deathmatch) | X | ⊢nZ∧P |
| League of Legends | X | ⊢P |
| MUD | ✓ | |
| WoW, ONE shard | ✓ | |
| WoW, all shards | X | ⊢1T∧1Sh[1S,Ix] |
| Facebook | X | ⊢VT[1T,SA,Ix]∧VS[1S] |
| the Internet | X | ⊢1T∧Rt[nZ]∧1Sh[1S,Ix] |

to real-world time), and so, real world events are recorded according to `ST` as they enter a system.[29] If the value of `ST` is recorded directly in the loaded state of software, the value represents "objective time"[29] (e.g., `Thu May 5 07:56:40 UTC+1 2016`), whereas if a value relative to the `ST` is recorded (e.g., elapsed time), the value represents "subjective time"[29] (e.g., an offset of 823 s, assuming the epoch of `ST`).

Software running in a computer (e.g., a virtual world engine[26]) will run according to `ST` but can simulate another abstraction of time, called `VT`, for its loaded state (e.g., a VE). `VT` can be simulated by establishing an epoch for `VT` (e.g., zero or `ST` when the state was loaded) plus an offset. Since `VT` can be altered independently of `ST`, it is precisely `VT` that allows a loaded state to be persisted to storage and reloaded (see Persistence), or time in a VE to be paused (see nonpausable), without side effects, for example, by shifting the epoch of `VT` or by pausing the increase of the offset, respectively.

## 4.2 | Shared temporality (`1T`)

Interacting agents, `HA` or `SA`, can cumulatively share abstractions of time (their timelines overlap): real world, hardware, `ST`, or `VT`. `1T` means agents are able to share simultaneously real-world time and exactly one (ONE) `VT`, with other agents or entities they are acting upon. The following are examples of how abstractions of time are cumulatively shared and not:

- people in a telephone conversation share real-world time;
- two players playing email chess and making moves at complete different times of the day (same time zone) do not share real-world time;
- two applications running simultaneously on the same machine share real-world time, hardware temporality, and `ST`; if each application implements a `VT` local to the application, applications do not share `VT`;
- two machines running simultaneously in different time zones do not share hardware temporality but can be synchronized to share `ST`, for example, a world time;
- two applications intermittently context switching do not share `ST`;

- two applications running simultaneously on different CPUs or hardware machines do not share hardware temporality;
- two applications time sharing VT (i.e., taking turns elapsing virtual time) can do this by not sharing real-world time;
- two agents in a VE with VT running on a single machine, share all abstractions of time simultaneously;
- and, finally, two clients connected to a VE distributed over MANY machines do not share ST if they are not synchronized but can still share VT.

REQUIRES:VT

## 4.3 | Real time (Rt)

For a VE to be considered real time (Rt; not turn based and not tick based, where agents must wait for other agents to complete their actions before a new round can begin[27]), it implies

- Agents can perform actions simultaneously[30] (the synchronous communication mentioned by Bell and Robbins-Bell[8] is a subset of this interaction);
- and the game world is available and action immediacy is part of the game design.[27]

Note that Rt is not the same as real-time computing constraints; Rt is contrary to turn based, whereas a VE with real-time computing constraints must complete computations before certain time deadlines. Performance is an issue for the Rt property, but missing deadlines does not constitute system failure as in real-time computing. Although latency reduces the feeling of Rt,[27] massive amounts of latency does not invalidate the Rt property for a VE; it just makes for a very slow VE, for example, massive space battles in EVE Online have been known to reduce graphics to a slideshow of images.[31]

## 4.4 | Virtual spatiality (VS)

Aarseth[32] states that "computer games are allegories of [physical] space." This is similar to the feature, determined by Singhal and Zyda[14], that net-VEs provide a "sense of space" for all participants. And similar to what Raph Koster refers to as a "spatially based depiction" of a VE[2[#33]]. Benford et al[25] have classified a scale of spatiality, with "containment only" on one end of the spectrum and a "shared spatial frame" (e.g., a Cartesian coordinate system) on the other, having identified "fundamental physical spatial properties such as containment, topology, distance, orientation, and movement." Movement is an important factor in VS[25], for example, in MUD[33] you move through seemingly continuous non-Euclidian space[23[p.28]] but in discrete steps; in a graphical world, the equivalent would be moving from pixel to pixel in the frame of reference.

## 4.5 | Shared spatiality (1S)

Singhal and Zyda[14] describe "a shared sense of space" such that "all participants have the illusion of being located in the same place, such as in the same room, building, or terrain. That shared place represents a common location within which actions and interactions can take place. The place may be real or fictional." Note that the description does not exclude single player games (i.e., technologies with just ONE human agent and SA), even though the net-VE, by Singhal and Zyda,[14] is described as a multiple user system. The description is problematic for two reasons: First, telepresence, where users see into each other's physical space, is included in the set of net-VEs. If the definition herein is for a "pure" virtual world, then "the place may be real" should be excluded. Second, "in the same place, such as in the same room, building, or terrain" is too restrictive. If "the same place" (see Places) can be understood as the same virtual world, with (possibly multiple) different terrain and physics (e.g., it is entirely possible to have different planetary worlds within the same virtual world, such as in WoW), then this part of the description is ok.

Benford et al[25] state that "Logically, the shared space in which a cooperative activity occurs can be defined to be those aspects of the system, which are independent of any single participant or group of participants and which are agreed on by the participants." This description is problematic, because the shared space of a virtual world is dependent on the architecture serving that world, for example, if 1S is to be "independent of any single participant or group of participants," then having a single participant or group of participants host the virtual world is not allowed. Property P handles the persistence of a shared resource (see Persistence).

REQUIRES:VS and 1Sh

## 4.6 | ONE shard (1Sh)

In an attempt to differentiate one world or many worlds, technologies can be examined to see if they are contained within ONE shared data space, ONE shard[†], rather than MANY. Two ways, to partition a VS to allow for scalability, are regions and shards.[5,34] Using regions, the VS is divided into static or dynamic areas, with each area handled by a different group of servers; players can still move throughout the entire VS. With shards, players are divided up into groups and assigned to a unique copy (a shard) of the VS, with each shard handled by a different group of servers; players are prohibited from moving between shards. Shards are copies of the same VS that do not synchronize with each other. Note, that a shard can be divided up into regions. To examine for the presence of 1Sh, technologies must be examined to see if players share a common

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[†]"This term is an Ultima Online fiction to explain how come there are multiple copies of a supposedly single world."[7]

data space; with regions players still share VS, with MANY shards, they do not.

## 4.7 | Size

Given VS, the property of size is added to this study as possibly characterizing a virtual world, that is, a VE that is too small or too big (e.g., a universe) can or can not be a virtual world. Bartle[7] states that, "virtual worlds imbue a sense of size" and that "size is affected by many factors." "If you can teleport anywhere, the world will feel smaller,"[7][p.261] that is, the "apparent size," the one perceived by the user, will be smaller. One way to judge "absolute size" is to calculate the number of discrete points in the environment and the speed of travel through the environment. But both the apparent size of an environment and how big the absolute size needs to be (i.e., a VE is worldly enough) are subjective. So size is not a determinant property of virtual worlds. Qvortrup[23][p.28] states that virtual (3D) space has the general property of being "geometrically finite, that is, it makes up a bounded, delimited world," but current computer systems are capable of simulating theoretically infinitely large virtual worlds, for example, in Minecraft.[35] The implementation of a VE largely dictates how freely a player can move through VS. The existence of teleporters invalidates the size metric further and does not differentiate between a world or multiple worlds. A world can be divided into "mini worlds" that have a free format and teleporters between them.[36]

## 4.8 | Indoor / outdoor

It can be questioned whether the indoor or outdoor nature of a VE characterizes a virtual world, for example, is both an open outdoor and an indoor space required for a VE to be considered a virtual world? Aarseth[32] specifies "two different spatial representations: the open landscape found mostly in the "simulation-oriented" games and the closed labyrinths found in the adventure and action games." Aarseth calls the open landscape "outdoor," and the closed labyrinths as "indoor."

However, the concept of indoor or outdoor is based on the perception of the user and the cultural aspects of the game. Aarseth[32] states that even from a cultural perspective, "what seems like an outdoors game is very much of the indoor variety: discontinuous, labyrinthine, and full of carefully constructed obstacles." From a technical perspective, there is also a problem, since the basic spatial property of a VE is said to be containment; all entities are contained within the environment and would be deemed indoor. Even a simulated infinitely large world is still contained within a VE. Indoor or outdoor is not a determinant property of virtual worlds.

## 4.9 | Places

Singhal and Zyda[14] describe a "shared sense of space" as a "shared place" wherein interaction can happen. It is unclear if words of the description were chosen with regard to the "space versus place" debate,[25] or not. Considering the social meaning of "place," it is only possible to create a space that has the opportunity to adopt meaning and become a place, for example, technology can create the space of a virtual world, but when it adopts meaning, the virtual world becomes a place; the same is true for spaces within a virtual world. A virtual world and the spaces within might be places, but since place is socially determined and already captured in the concept of a world, place is not a determinant property of virtual worlds.

## 4.10 | Things or phenomena

Simulating things or phenomena means implementing in software a game object[‡] with the most trivial needed properties (e.g., position, orientation, description, or visual representation) and deriving more advanced game objects by adding functionality or specialization to the derived game object. Even entities, such as the ground to walk on or water, might be implemented as a single or collection of game objects. For environmental effects such as lighting or heat that have a source but where only the effect is modeled, the effect is often attributed to the environment, for example, the sun produces heat, but the sun is not modeled, only the effect of temperature on other game objects. A world will contain both ephemeral things, such as spoken words, and nonephemeral things, such as rigid bodies. Supporting the nonephemeral requires the world to support P. If SA is supported, then the system is rich enough to support things and phenomena also.

REQUIRES: SA

## 4.11 | MANY human agents (HA)

A VE with exactly zero (ZERO) humans can be equated to that of a pure simulation, for example, a MUD where no players ever connect. Analyzing technologies for their support of one, two, three, four … and an increasing amount of humans leads to a subjective debate on how many humans is enough for a VE to be considered a virtual world, for example, Bartle[19] estimates that 100,000 players would be enough to constitute a massive world by today's standards, and Yahyavi and Kemme[36] state a massive game is capable of supporting hundreds or thousands of players.

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[‡]"The collection of object types that make up a game is called *the game object model*. The game object model provides a real-time simulation of a heterogeneous collection of objects in the virtual game world"[37][original italics].

## 4.12 | MANY software agents (SA)

Because a virtual world is a simulation, one can attempt to simulate HA. Van de Velde[38][original italics] states that "The concept of *agent* refers to a system that can be differentiated from its environment and is capable of direct and continued interaction with that environment. Such a system "exists" in its environment and has with it an observable interaction, which is called its *behavior*." Shoham[39][pp.271–2] has defined a *software agent* to be one "that functions continuously and autonomously in an environment in which other processes take place and other agents exist. [ … ] The sense of "autonomy" is not precise, but the term is taken to mean that the agents' activities do not require constant human guidance or intervention."

If VT is supported[§], agents that activate at a regular interval are considered running continuously. According to Russell and Norvig[40][p.39], an agent that lacks autonomy "relies on the prior knowledge of its designer rather than on its own percepts [ … ] A rational agent should be autonomous—it should learn what it can to compensate for partial or incorrect prior knowledge," that is, autonomy assumes learning. The more relaxed definition of an autonomous agent, by Shoham,[39] is adopted here, which does not assume learning. According to Russell and Norvig,[40][p.39] the most simple agents possible are simple reflex agents, which "select actions on the basis of the current percept, ignoring the rest of the percept history." It is through SA, that if a virtual world has ZERO users, the simulation will produce events, that is, develop internally.

REQUIRES:VT

## 4.13 | Virtual interaction (Ix)

"The concept of 'interaction' generally means 'exchange,' 'interplay,' or 'mutual influence'"[23][p.34]. It is important to make the distinction between the exchange of interaction and the "to act upon" or "react to a stimulus," for example, users act upon user interface entities and a player might react to the stimulus of heat or gravity. In order for exchange to be possible, agents other than humans, must be capable of interaction, for example, SA. This property means that users can both interact with people[9] (other HA in the virtual world) and "interact" with the world[9,19] (interact with SA and act/react to things and the environment). Both the "a way to communicate" and "a way to share," referred to by Singhal and Zyda[14][p.3], is not handled separately but categorized here under Ix. If two virtual entities are to interact, they must have virtual proximity,[23] requiring the entities simultaneously share time (1T) and space (1S), that is, they must share simultaneously real-world time and ONE VT.

REQUIRES:SA, 1T, 1S and by consequence 1Sh

## 4.14 | non-Pausable (nZ)

Considering the set of technologies that support Rt, there is a subset that have an "active pause system,"[30] that is, if VT is supported[¶] , agents can be allowed to effectively freeze VT relative to real-world time. Satisfying the nZ property requires the absence of an active pause (or that its use is limited to operators only, for the purpose of maintenance). According to Bell and Robbins-Bell,[8] the nZ property is part of P.

REQUIRES:Rt

## 4.15 | Persistence (P, world (wP), data (dP)) and Pseudo-

Bartle states that a persistent virtual world "continues to exist and develop internally even when there are no people interacting with it."[7] The criterion that a virtual world should "develop internally" is handled by SA, which constantly alter the world (e.g., as in MUD). Later, Bartle revised his persistence criterion, removing the need for internal development, stating "if you stop playing then come back later, the virtual world will have continued to exist in your absence."[19] Bell and Robbins-Bell[8] use Bartle's original criterion, considering P to differentiate video games and virtual worlds on the basis that, "a virtual world cannot be paused"; pausing is handled by nZ. Bartle's criterion that the world must "continue to exist" can be referred to as "world persistence" (wP),[17] that is, the world continues to exist and is available to the players when they want to access it. To ensure world data is not lost in the event of system failure, the system must support "data persistence" (dP)[17,26] for all data spaces that hold nonephemeral data. It is precisely VT that allows for a loaded state to be persisted to storage and reloaded without side effects; without the abstraction of time, that world's time would freeze during storage, suddenly rewind on a rollback or fast forward to the current real-world time on load. A hybrid based on ST and VT is possible but then the world would be mixed reality (see Mixed Reality below).

The problem with persistence is that it can be simulated, without raising awareness to the player, for example, if a world is made available to players at all times, they want to access it; it is seemingly always in existence. A straightforward way to achieve this is to have scheduled play times

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[§]It is possible to run agents off other temporalities (e.g., ST using objective or subjective time), but in order to be able to persist the state of the agent (see Persistence) and maintain a pure virtual world (see Mixed Reality in Section 6.3.5), VT is required.

[¶]Those technologies that do not support at least one shared VT (V or V+ in Section A.2) are automatically nZ (unless not Rt). A computer system usually only allows for the setting of ST (the current time) but not pausing relative to real-world time, that is, becoming unsynchronized.

around down times.[26] The simulation of P can be generalized as pseudo-persistence.[17] Taking pseudo persistence into account, Bartle's original definition of P is superior to that of 2010, because a world can be kept in existence through player interaction, simulating wP.[17] To simulate dP, world data can be loaded and made available at specific times when players, relevant to that data, are playing.[18] A straightforward way to simulate dP is to avoid needing it, that is, simply have no data to keep track of.

Also related to virtual worlds but not to be confused with wP is the concept of "game world persistence,"[17] that is, events and activities in the game world that do not "reset"[3,41] and are not interrupted by real world events (e.g., a bathroom break). Because game world persistence is from a cultural perspective, the concept is beyond the scope of this article.

## 4.16 | Centricity

Centricity is defined by Milgram and Colquhoun[21] as "the extent to which a human observer's viewpoint is removed from the 'ownship,' that is, from the nominal viewpoint with respect to the viewer's own avatar, or own vehicle, or own manipulator within the task space." The concept of centricity is generalized into a continuum between "egocentric" and "exocentric,"[21] with illustrative intermediate points being ego referenced, tethered, or world referenced. In a 3D world, a first-person perspective can be created using an ego-referenced viewpoint and a third-person perspective through either a 3D tethered (sometimes referred to as over the shoulder) or a 3D world-referenced viewpoint.

Qvortrup[23[p.30]] defines two avatar categories: "user-in-avatar, which is a representation of the human user in the virtual 3D world and the designer-in-avatar, which is a representation of the designer, developer, or creator of the 3D world (sometimes called God)". These two categories can be enabled using various grades of centricity; the ego-referenced and tethered viewpoints can be used for the user-in-avatar representation, whereas world-referenced viewpoints can be used for the designer-in-avatar representation.

Centricity is difficult to apply to a technology that is not 3D (e.g., text-based interfaces) and many technologies offer multiple viewpoints with option to switch between them (e.g., in WoW); such a change does not effect the worldliness of the VE or whether an avatar is present (see MANY Avatar). Centricity is not a determinant property of virtual worlds but a way to visualize them (see Visual Representation).

## 4.17 | Mediation

A desktop class computer has been typically used in the past to access virtual worlds. As computing capacity rises in handheld devices (e.g., tablets and smartphones), they too

are being used to access virtual worlds. How a virtual world is accessed (i.e., the mediating technology) does not and should not determine its worldliness, for example, accessing a text-based MUD on a modern smartphone does not effect the MUD. A virtual world might be accessed simultaneously by the same user through different devices, and each device might offer a different functionality. Additionally, who knows what technology will be used to access future virtual worlds, for example, head-mounted displays.

## 4.18 | Visual representation

It is possible to have multiple representations of the same world simultaneously on different different devices, for example, supporting crossmedia. This means that the visual representations of the game (e.g., text, 2D, 2.5D, and 3D) is not a determinant property of virtual worlds.

## 4.19 | Communication architecture

Various communication architectures can be used to allow clients to connect to a virtual world, for example, local on computer or device; client connecting to single server or a cluster of servers; peer-to-peer systems with or without additional infrastructure; or many clients connecting to a cloud-computing platform.[36] A particular communication architecture is often chosen to gain scalability or maintain control over the world.[36] Although networking is required to support HA, there are virtual worlds that allow for both local and network access (e.g., MUD[19]). The property of communication architecture does not classify virtual worlds, because it is widely used by diverse communication tools, games, and web services, that is, communication architecture is not a determinant property of virtual worlds.

## 4.20 | Online

When virtual worlds are discussed, the property of the VE being online is sometimes brought into the discussion.[1] As per the definition[20] accessing something online means "with or through a computer, especially over a network." This property is therefore broken down into HA and communication architecture.

## 4.21 | MANY avatar (Av)

Described as "extensions of ourselves"[23[p.26]], there are many definitions of the term "avatar." Bartle[19] describes an avatar as a "virtual self" where "each player identifies with a unique entity within the virtual world (their character) through which all their in-world activity is channelled." According to Bell and Robbins-Bell,[8] "any digital

representation (graphical or textual), beyond a simple label or name, that has agency (an ability to perform actions), presence, and is controlled by a human agent in real time is an avatar."

The real-time aspect is handled by $Rt$. There is ambiguity in the situation where a player, in a single user environment, has an ego-referenced viewpoint, that is, they can not look at themselves, (e.g., in Zork[42] or in first-person perspective in a 3D environment); if no digital representation is present, does the player actually have one? Even without an avatar, $SA$ must be able to react to the presence of the player, that is, some entity. In this regard, Bartle's definition of the virtual self is superior to that of Bell and Robbins-Bell[8]; since the virtual self is defined as an entity through which presence can be detected and interacted with, rather than a graphical or textual representation.

Although it is often true that virtual worlds assign a unique entity to the player, there is evidence that this is not a requirement. For example, in WoW, there are users that purchase multiple accounts and control multiple avatars simultaneously through multiple installations of the game; a technique that has been referred to as "multiboxing."[43] Because multiboxing can be used to override the unique avatar feature of WoW, the definition by Bartle[19] shall be used here but without the uniqueness criterion, that is, MANY avatar. It is understood that the uniqueness criterion is meant to exclude worlds where a user is not embodied in a unique entity and able to interact in the world (e.g., when controlling a large collection of units), but as of this writing, no technical property was found to discriminate worlds accordingly.

## 4.22 | Immersion

Immersion has been researched in different domains, for example, virtual reality, game research, and interface design.[44] Immersion is a qualitative property tied to the perception of the user, so it would seem that creators of virtual worlds can only aim for an immersive experience, that is, immersion is not a determinant property.

Benford et al[25] introduce the dimension of "transportation" (which they compare with immersion), which "concerns the extent to which a group of participants and objects leave behind their local space and enter into some new remote space in order to meet with others, versus the extent to which they remain in their local space and the remote participants and objects are brought to them." With respect to defining a virtual world, the dimension is problematic, for example, augmented reality, projected collaborative VEs, and immersive collaborative VEs are on very different parts of the transportation continuum, but each of those VEs could be a virtual world. The extent to which a user leaves their local space behind does not determine if the VE is a world.

## 4.23 | Presence

A sense of presence is sometimes used interchangeably with immersion,[4] remarked as being required for immersion[44] or vice versa.[45] Like immersion, presence is also a qualitative property tied to the perception of the user, that is, presence is also not a determinant property for virtual worlds.

## 5 | ANALYSIS AND RESULT

The aim of this work is not to evaluate how virtual-like or world-like a virtual world is but to find a definition that delineates what is and is not a virtual world, for example, a 3D virtual world with multiple players, a vast many places to visit, totally immersing each player might feel much more worldly than a MUD, but the definition should not exclude a MUD from being a virtual world.

## 5.1 | The logical $\wedge$ of properties $(\forall p : \wedge)$

Having examined individual technologies (see the Appendix) for the properties pertaining to virtual worlds (that are found in the subsections of Section 4), those properties are collected that together classify well-known virtual worlds, for example, MUD, localhost or with networking, and WoW. In this section, the resulting properties (see Tables 1 and 2) of $1T$, $Rt$, $1S$, $1Sh$, $SA$, $Ix$, $nZ$, $P$, and $Av$ are assembled into a definition and the outcome justified.

### 5.1.1 | Real-time shared spatiotemporal VE

$VT$ ensures the world has its own time, independent from other times. A (not purely) virtual world can be built based on $ST$ (without $VT$), but all events related to $ST$ are subjected to being rewound or fast forwarded, in the case of rollbacks or downtime, respectively. $VT$ works together with $P$, ensuring events persisted to disk are independent of $ST$, that is, $VT$ can be translated along the timeline relative to real-world time and $ST$, without effecting time-based in-game events. The $Rt$ property excludes turn-based, tick-based, and any other technologies that do not support agents simultaneously interacting with the world. $1T$ combined with $1S$ ensures that the VE conforms to a spatial representation with the likeness of a world and that agents share that world.

### 5.1.2 | Shared spatiality within ONE shard

If a technology has more than one data space, $1Sh$ dictates that those spaces must be merged at one point or another for them to be considered one virtual world; each other copy or shard is considered another world. The question at hand is how to deal with instances, that is, are they part of the virtual world or not? A solution is to judge each shard on its

own merits as to whether it classifies as a virtual world or not. An instance can be considered a temporary shard (a copy of space to which a group of players is assigned), but not a virtual world, if it does not support the required properties, for example, P. In Diablo,[46] the virtual lobby is not a virtual world, because it lacks properties such as VS. And the world instances are not virtual worlds either. If the world instance would constantly synchronize with the virtual lobby, the lobby would provide P for the instance. It is specifically the 1Sh property that allows for a virtual world to be divided in a distributed system but still remain one world. 1S and 1Sh are combined to determine if technologies have a shared spatiality captured within ONE shard.

### 5.1.3 | Interacting agents and things

As discussed in Section 4.11, most technologies (e.g., except a pure simulation of a world) support HA. Bartle's criteria states that a persistent virtual world "continues to exist and develop internally even when there are no people interacting with it." From this, it can be ascertained that the world must support ZERO humans, that is, a world that suddenly has no people connected to it does not loose its worldliness. This would then also allow for a virtual world to be created for dogs or other nonhumans. If a world is to continue to develop internally with ZERO humans, the world must support entities that can take action, that is, support for SA determines if there is enough potential intelligence in the system to cause sufficient worldly change. Combined with Ix and the shared spatiotemporal VE from above, this means humans can potentially virtually interact, in the same time and space, with other HA or SA, or act or react to things and the environment. A technology that just supports HA is a communication technology but not necessarily a virtual world.

### 5.1.4 | Persistent virtual world

P ensures the world is available to HA when they want to access it and where nonephemeral changes in the world are preserved. P combined with the shared spatiotemporal VE from above ensures that the world is not a fleeting transient event. To satisfy the criteria by Bartle,[7] P is combined with SA. To satisfy the criteria by Bell and Robbins-Bell,[8] P is combined with nZ, a property that seems to effectively segregate virtual worlds from video games, when combined with P. The result of these combinations is a real-time environment that is nonpausable where agents produce lasting change.

### 5.1.5 | Virtual self as avatar

Singhal and Zyda[14] define a net-VE as a multiuser environment, with each user represented as an avatar; users need a representation through which other users can detect presence and interact. Although it might simplify the definition, no

assumption is made here that a virtual world is required to be multiuser, so a single user environment is still acceptable. The uniqueness criterion for a virtual self has been dismissed on the grounds that multiboxing does not alter the worldliness of a virtual world; Av is the virtual entity, which Bartle has defined as a "virtual self," with the uniqueness constraint dropped, so that agents (HA or SA) have something to interact with. If MANY avatars are present, at least one avatar must be present in the shared spatiotemporal VE from above.

### 5.2 | Definition: virtual world

Having combined the determinant properties, it is now possible to state the definition for a virtual world (VW) as

**Definition 1.** *A simulated environment where* MANY *agents can virtually interact with each other, act and react to things, phenomena and the environment; agents can be* ZERO *or* MANY *human(s), each represented by* MANY[‖] *entities called a virtual self (an avatar), or* MANY *software agents; all action/reaction/interaction must happen in a real-time shared spatiotemporal nonpausable virtual environment; the environment may consist of many data spaces, but the collection of data spaces should constitute a shared data space,* ONE *persistent shard.*

Properties not used in Definition 1 can instead be use to distinguish between different virtual worlds rather than classify a virtual world.

Girvan[9] offers the properties "3D, educational, goal orientated, graphical and user-generated content." 3D and graphical can be generalized to the visual representation of Section 4.18, and the following unused properties from the analysis in Section 4 can also be used: size, indoor or outdoor, centricity, mediation, communication architecture, immersive, or various degrees of presence. Some additional properties not mentioned in the analysis are number of players, theme (e.g., fantasy and science fiction), strategy type (e.g., RPG, PvE, and PvP) and in-game communication possibilities (e.g., chat and VoIP).

## 6 | VERIFICATION

In this section, Definition 1 is first verified against the prominent existing definitions mentioned in related work. Thereafter, a form of "discriminant sampling"[16] is used, that is, selecting advanced contemporary technologies that were not in the study to see if the theory holds true for these additional samples, classifying advanced technologies, such as a pseudo-persistent video game, a MANet, virtual reality,

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[‖]Keep in mind that MANY means "one or more," that is, a virtual self is not required to be unique.

mixed reality, and the Metaverse. The effectiveness of the obtained definition is demonstrated by creating an ontology of virtual worlds, that is, clarifying acronyms commonly found in research and popular discourse.

## 6.1 | Definition comparisons

A virtual world can be classified as a net-VE,[14] where the multiuser restriction is relaxed to allow for local play and simulations with no humans; the environment is required to be persistent. A shared sense of space and a shared sense of time can be assumed to be equal to the shared real-time spatiotemporal VE in Definition 1, except for one problematic sentence in the definition. Singhal and Zyda state that the place in a shared sense of space, may be real or fictional. It is assumed that this statement is mentioned to include the physical aspect of a video conference but not meant to include "pervasive systems."[26] If the latter is the case, there is not enough clarification provided in the rest of the definition to handle pervasiveness (see Mixed Reality), for example, a virtual persona projected into the physical world would seem to be included in definition, but a human interacting with that projection in the physical shared space fails the avatar requirement by Singhal and Zyda. A shared sense of time by Singhal and Zyda implies real-time interaction, but in Definition 1, it is made explicit. A "shared sense of presence" implies support for avatars that can be "synthetic entities"; again this aspect is made explicit in Definition 1 through requiring software agents. The need for an avatar, mentioned in the shared sense of presence, is a consequence of a net-VE being defined as a multiuser environment. It is not clear if the avatar requirement has a uniqueness constraint. A "way to communicate" and a "way to share" are considered part of action and interaction in Definition 1, with the different types of in-game communication left as not determinant of a virtual world, rather, a distinguishing characteristic of various virtual worlds. Using the two definitions, Google Docs[11] classifies as a net-VE but not as a virtual world.

Bartle[19] updated his definition of a virtual world and the persistence criterion, stating a virtual world to be "an automated, shared, and persistent environment with and through which people can interact in real time by means of a virtual self". The automated property specifies a set of rules by which players can change the world, but does not mention how the world can develop internally (previously, a part of $P$[7]). The definition refers to a shared environment, where "more than one player can be in the exact same virtual world at once," but usage of the term virtual world in the description leads to a recursion; it can be assumed to mean a shared spatiotemporal VE, but if the description is to serve as a definition this is problematic. The definition mentions interaction within the virtual world for people but does not mention virtual inter-

action in the world, for example, software agents. Bartle[19] altered the persistence criterion to state "if you stop playing [and] then come back later, the virtual world will have continued to exist in your absence," but Bartle's[7] original definition of $P$ is superior to that of 2010 (see Persistence). The persistence criterion can be assumed to include the nonpausable criterion, by Bell and Robbins-Bell, but fails to account for the difference between persistence in a single player video game and a virtual world. Bartle's definition of a virtual self has been adopted in Definition 1, but the uniqueness criterion has been dropped. Since time and space are not elaborated on, the definition by Bartle can be said to describe a persistent communication technology, that is, including virtual worlds, but also including technologies such as Google Docs.

Through literature review, Bell and Robbins-Bell[8] offer the definition of "a synchronous, persistent network of people, represented as avatars, facilitated by networked computers." The term "synchronous" in the definition refers to synchronous communication. Although this seems to be similar to $Rt$, synchronous is only applied to communication in their definition; $Rt$ requires real-time interaction, which includes communication. The term "synchronous" is also ambiguous when referring to communication, for example, Bell and Robbins-Bell[8] state "a synchronous environment does not require the sender of a message to wait for the other party," whereas an synchronous communication protocol is one where the sender does wait for a response. Bell and Robbins-Bell offer a citation for synchronous communication, but the underlying reference simply ensures that users are logged-on simultaneously, which is irrelevant in determining real-time interaction when both users are indeed logged on.

Synchronous communication is said to imply the concept of continuous common time (similar to $1T$) and bring about a sense of presence. Bell and Robbins-Bell use Bartle's criterion for persistence from 2003, but add that "a virtual world cannot be paused," differentiating them from video games. This criterion has been adopted in Definition 1. A "persistent network of people" is mentioned in their definition, but persistence and a network of people is handled separately in their text; a persistent network of people is not the same as a world that stays in existence, unless worldliness is only defined in function of people. Linked to synchronous communication, Bell and Robbins-Bell refer to social grouping behavior and a primitive form of ecosystem, leaving a "network of people" to mean the social construct. In Definition 1, single user environments are allowed, not requiring a form of social networking, although social networking might be probable in a multiuser virtual world. Bell and Robbins-Bell define an avatar and state that it should have agency (e.g., a Facebook profile does not have agency beyond its creator), functioning "like user-controlled puppets." Users command the actions of the avatar, but it is the avatar itself which performs the action." This view would seem to deny an immersive

ego-referenced perspective that virtual reality strives for (the reader is referred to Waggoner[47] for a discussion on this matter). The definition of a virtual self, by Bartle,[19] was adopted in Definition 1, because it provides an entity for other agents to interact with. The criterion "facilitated by networked computers" serves to ensure an environment simulated by computers is being referred to and that those computers are networked. Definition 1 does not require multiple users or networking, allowing for virtual worlds that are pure simulations.

Girvan[9] states a virtual world to be "a persistent, simulated, and immersive environment facilitated by networked computers, providing multiple users with avatars and communication tools with which to act and interact in world and in real time." The definition is compiled through literature review, but the sampling is heavily biased towards Second Life,[10] with 47 out of 68 surveyed articles referring to Second Life. Definition 1 agrees with many of the properties in this definition, but "immersive" has been identified as a qualitative property that is subjective; as in the case of a net-VE above, Definition 1 does not require multiple users or networking; and Girvan does not define shared time or space, which is especially problematic when dealing with video games, instances or ad hoc networking. Definition 1 is similar to the one from Girvan, in the sense that action and interaction are handled individually.

## 6.2 | Ontology of VE

If the net-VE definition by Singhal and Zyda[14] is used (assuming that multiple users (MU) implies networking) and Definition 1 is used for a virtual world, then

- a VE that supports MU is then a MUVE, and equal to a subset of net-VEs;
- there is a subset of MUVEs and net-VEs that support persistence[9];
- the subset of net-VEs that support persistence is a subset of the virtual worlds (VW; according to the Definition 1) that support MU;
- since online implies both virtual and networking, a VW that supports MU is equal to an online world (OW);
- an OW supporting massive multiplayers (MM) is an MMOW;
- a VE supporting MM is then a MMVE;
- an MMO that is a game is an MMOG,[37] of which some are MMOWs[10];
- and finally, a MMOG that is of the role-playing type is an MMORPG, with the RPG type implying a MMOW that can be role-played in[37].

The ontology for the acronyms is displayed in Figure 1 and 2 (in no way does the size of the drawing imply the number of members in the set). The set of net-VEs contains the
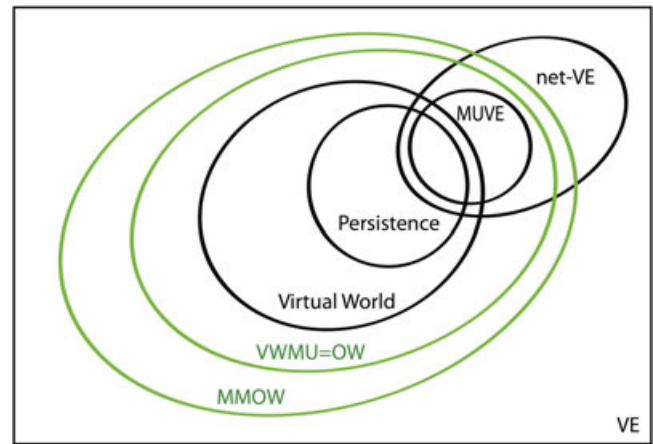


**FIGURE 1** Ontology of virtual worlds in relation to net-VEs and other sets. net-VEs = networked virtual environment
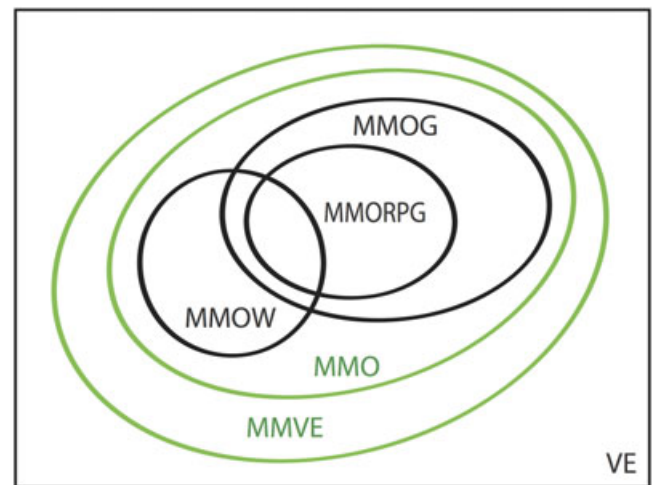


**FIGURE 2** Higher level ontological view of MMO's and the set of MMVE

properties of: 1T, Rt, 1S, SA, Ix, Av, MU, and networking; the set for virtual worlds contains: 1T, Rt, 1S, 1Sh, SA, Ix, nZ, P and Av; meaning a discrepancy on: 1Sh, nZ, P, MU and networking. The set of VWMU or OW contains the additional properties of MU and networking; all sets starting with 'MM' have the massive multiplayer property; and the general VE has the properties of being simulated, spatial containment, and MANY data spaces.

As seen in Girvan[9], these acronyms can be further coded with optional qualifiers (see the Definition section) to create more subsets, for example, in the case of a virtual inhabited three-dimensional worlds (VI3DWs)[23][p.25] or an immersive virtual world (IVW).[9] Interestingly about the latter example, is that if all virtual worlds were by definition immersive as in Girvan,[9] the term immersive would be redundant in the acronym.

## 6.3 | Evaluation using discriminant sampling

In this section, to further evaluate Definition 1 and the underlying determinant properties, discriminant sampling[16] is used, that is, selecting advanced contemporary technologies that were not in the study to see if the theory holds true for these additional samples. But first a clarification on the nuances that separate MUD and IRC.

### 6.3.1 | MUD and IRC

A simulation of a world, is the only technology that fails to support HA, and therefore could be said to fail for VT, that is, if the allegory of physical space of MUD is created through narrative and there are ZERO humans to understand the narrative, then the allegory should be lost. WoW simulates an allegory of space, which is not based on narrative; if all players disconnect, software agents must still perceive an allegory of space. MUD has software agents, which minimally understand the narrative (e.g., go south) and therefore still perceive an allegory of space, leaving a MUD with ZERO players to satisfy VT.

If scripting on IRC is included in the discussion, it is difficult to distinguish the technologies of MUD and IRC. IRC fails to have a shared spatiotemporal VE; failing SA and Ix as a consequence. An IRC "bot" on a single IRC network can be created to make use of ST, so this bot can scripted to be a continuous autonomous software agent. A user of IRC can change "channels" with commands (similar to MUD) and each channel has a welcome statement (similar to a room description in MUD). Taking all this into account, the IRC network would satisfy all the properties, except one, to be considered a virtual world (albeit an empty one, since IRC has next to no world or player data that needs to be persisted). As soon as IRC was made more worldly, P would become critical for persisting SA and things that agents carry around or are lying around.

### 6.3.2 | Destiny

From the analysis, it is apparent that it is difficult to differentiate between video games and virtual worlds. The only properties that seem to differentiate them are nZ and P. Centricity was accepted as a determinant property until a game similar to LoL, called Smite,[48] was found that is ego referenced rather than world referenced. LoL only supports pausing under strict conditions (e.g., in tournament play) and so could be said to support nZ. Persistence is the only criterion left as the "defining characteristic with which to distinguish between video games and virtual worlds."[9]

In the analysis, Diablo and LoL were classified as pseudo-persistent worlds. Pseudo persistence is a powerful tool that can be used to blur the lines between video games and virtual worlds, for example, through the use of instances. In the game called Destiny,[49,50] the universe is created by replacing the virtual lobby, of Diablo and LoL, with "seamless background matchmaking."[49] The universe is made up of instances called "bubbles," which connect with "Activity Hosts" and a "WorldServer." A single bubble is standardized to simultaneously support six players and 25 software agents; Activity Hosts are cloud-based machines that run missions logic; and the WorldServer persists all character and progression data, using cloud computing.[49] A bubble is hosted seamlessly on either a player's console (a private bubble) for peer-to-peer play or hosted in the cloud (a public bubble), if it is a public event. Destiny's architecture is still only pseudo persistent and not a virtual world according to Section 5.1.2. The WorldServer can not be judged as a virtual world, since the spatiotemporal VEs are the bubbles. And the bubbles are not virtual worlds either, since they are copies of space and lack persistence.

### 6.3.3 | Transhumance

Söderlund[18] describes how a pseudo-persistent world can be created using ad hoc networking, for example, using the Transhumance platform, where the collection (a fog, rather than a cloud) of devices forms the world. The Transhumance middleware platform concentrates heavily on security and power consumption[51] but is rich enough to implement the pervasive game called Team Exploration.[52]

Paroux et al[51] do mention a "time-limited mode" for group creation but do not go into detail on how time is implemented, for example, how time is synchronized between all devices. It is assumed that ST is used, pending research pertaining to VT on MANets. Each user has their own device, so no turn taking is needed, that is, satisfying Rt. The spatial representation of Team Exploration is an allegory of physical space, because it models that space. A player's location in the virtual is mapped to their physical location and could be depicted on a virtual map. Even though the player must move through physical space to move virtually, it can not be denied that VS is present. Team Exploration supports 1S, because all players of the game share the same virtual space. Transhumance provides for 1Sh, where the fog of devices can form a common shared data space.[51] If nodes are out of reach, network partitions may occur where no route can be found between two nodes.[52] As long as the common data space does not become partitioned, the Transhumance platform forms ONE shard, else each partition becomes a separate shard.

Each device has its own data space, which can be considered a temporary instance when not merged. Further changes, on previously merged devices, that have become partitioned are not part of the shard unless synchronized again. Game mechanics can be put in place from a cultural perspective, to entice players to meet, so that data spaces merge,[26] for example, in Transhumance, all members of the team had to be network connected to each other (in proximity) to solve

a puzzle.[52] No mention of `SA` was found in the references, but it is assumed that it would not be impossible to implement them. In the absence of `VT`, agents would have to be activated according to `ST` (i.e., mixed reality). Because `SA` is not supported, `Ix` is not satisfied either. Transhumance is assumed to use `ST`, satisfying `nZ`. During a pervasive gaming session, the platform can provide for a pseudo-persistent world through the fog of devices. Individually, each device in the fog is vulnerable to failure (not supporting `dP`), but Transhumance enables a degree of persistence by having users of a group host data for other members of the group.[51] And lastly, nothing like an avatar was found in reference to Team Exploration; a player's own location is not shown on the map and neither the location of other players connected to their device.

Because `VT` is mapped to physical spatiality, and `ST` is assumed to be used, the Transhumance platform classifies as a mixed reality technology, that is, with mixed reality interaction (not `Ix`) . If `VT` was present, `SA` implemented with `Ix`, and players provided with `Av`, the Transhumance platform could provide for a pseudo-persistent mixed world.

### 6.3.4 | Virtual reality

Coquillart et al[4[p.v]] describe virtual reality as "interactive human-computer–mediated simulations of artificial environments." Only some of those artificial environments will be virtual worlds according to Definition 1, leading to the statement, by Dionisio et al,[5] that virtual worlds "constitute a subset of virtual reality applications."

### 6.3.5 | Mixed reality

Milgram and Colquhoun[21] present a continuum for mixed reality, between the virtual and physical. Benford et al[25] describe mixed reality as a shared space that integrates the dimensions of the local and remote, and the physical and synthetic. If `VT`, `VS`, `SA`, `Ix`, or `Av` have been "mapped" to a physical counterpart, then the world should fall on the continuum in between the pure virtual and physical. Note, that because WoW makes use of both `ST` (e.g., for the day/night schedule) and `VT`, to be precise, that would make WoW not purely virtual, that is, a mixed world.

### 6.3.6 | The Metaverse

According to Definition 1, the Internet fails to be a virtual world, failing the criteria of a `1T`, `Rt`, `1Sh`, and `P`. Because the Internet has multiple spatiotemporal shards, the Internet is perhaps more closely related to a "world of worlds"[19] than one world. Dionisio et al[5] call a future topology for multiple virtual worlds "metagalaxies" or the "Metaverse." The key difference between the Internet and the Metaverse, is that the Metaverse would support `Rt`. Because the Internet is already mixed reality (e.g., with video conferencing, web cameras depicting a live video feed of cities in the physi-

cal world, tele-operations, and projections from the net onto buildings), it is possible to conclude that the Metaverse will be necessarily mixed as well.

### 6.3.7 | The Matrix

By entertaining the concept found in the movie The Matrix,[53] Definition 1 can be tested to see if it is future proof. If Neo takes the "red pill" and finds the real world is actually a simulation, is the real world a virtual world according to Definition 1? To start, the current real world can be renamed to the Matrix. The "new" world that Neo discovers can then be called the "real" world. Matrix time is then an abstraction of time equal to that of `VT`. Two human agents, Neo and Trinity, accessing the Matrix from their real world, share real-world time and Matrix time (`VT`), satisfying `1T`. The Matrix supports `Rt` and `1Sh`[**] (as we know of today).

The Matrix has `SA`; Neo and Trinity can interact with each other in the Matrix, and act and react with the Matrix itself; Matrix time is `nZ`; the Matrix supports `P`; and each agent of the Matrix is given an `Av`.

In addition, the Matrix offers ego-referenced centricity and a tethered-referenced view (or perhaps a world-referenced view for those who have an outer body experience). The Matrix is rendered directly in the minds of its users, Neo and Trinity. The communication architecture the Matrix runs on is left as the fiction depicted in the movie.

## 7 | CONCLUSION

The primary result of this article is a detailed definition for a virtual world, with all underlying terms defined. The definition is applied directly to technology for classification, showing which properties set apart the different technologies. Remaining properties that do not determine a virtual world are listed so they can be used to distinguish between virtual worlds. The implication of this article is to provide a definition that is detailed enough to be adopted by the research community. The novelty in using grounded theory to classify technologies that implement a virtual world is that if a new technology emerges, it can be handled. If the new technology challenges the current theory, properties can be added to the theory and the definition updated.

Herein, a definition has been derived for a technology that IS-A virtual world. As future work, perhaps a definition can be derived for a technology that HAS-A virtual world, for example, by relaxing the `nZ` criterion (technology perhaps HAS-A virtual world when a player has control over time through pausing) or using the properties of centricity or

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[**]A MUD, inside the Matrix, is then contained in a shard nested inside the shard of the Matrix. The users in the Matrix are segregated from the users inside MUD and users are prohibited from "physically" moving between the shard and nested shard.

presence. It could be argued that a game such as Civilization V[54] HAS-A virtual world wherein a player moves games pieces, mimicking a board game. Perhaps Bartle[19] specified the uniqueness criterion for a virtual self in an attempt to delineate when a technology is IS-A virtual world, classifying technologies with MANY virtual selves as the likeness of a board game that HAS-A virtual world. In addition, a qualitative analysis characterizing the worldliness of a virtual world could prove useful, for example, how many is "MANY" or do more believable SA contribute to the worldliness of world?

## ACKNOWLEDGEMENTS

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## APPENDIX A

(I) MUD[33] and (II) World of Warcraft (WoW)[13] were immediately added to the sampling set, a characteristic first generation virtual world and a characteristic contemporary massive multiplayer virtual world, respectively. Thereafter, technologies were added that would separate the digital world from the virtual, that is, a (III) calculator[55] and (IV) graphics calculator.[56] (V) Email chess[28[Correspondence chess]] was added, because it is a two-player game, involved turn taking and also included networking. MUD is text-based, so a single user word processing application was added, that is, (VI) Microsoft Word[57]; and also a word processor utilizing networking for collaborative editing, that is, (VII) Google Docs (GDocs).[11] To differentiate on static or animated drawing, (VIII) a CAD application[58] was added to the sampling set, taking into consideration with and (IX) without animation. (X) A telephone call[28] and (XI) television[28] were added, due to the discussion by Combs et al.[2] This led to the addition of a virtual variant of the telephone, (XII) Skype,[59] and also the question of how chat compares, for example (XIII) IRC.[60] To differentiate MUD from its predecessor, (XIV) Zork[42] was added. To differentiate between the various virtual worlds, (XV) Ultima Online,[61] (XVI) Big World Technology[62] and (XVII) EVE Online[24] were added; the first two because they used shards and regions, respectively, and the latter because of its architecture and science fiction outer space theme. (XVIII) Diablo[46] was added due to it being a video game and it being discussed by Combs et al[2]; the contemporary variant (which also uses a virtual lobby) (XIX) Leagues of Legends (LoL)[12] was also added. (XX) Elite: Dangerous[63] was added, because of its use of instances. As a graphical modern variant to turn-taking email chess, (XXI) Civilization V (Civ5)[54] was added. (XXII) Doom[64] was added because it is a classic first-person shooter in 3D. The social network called (XXIII) Facebook[65] was added because it is discussed by Bell and Robbins-Bell.[8] The addition of (XXIV) Second Life,[66] is due to it being a virtual social community. (XXV) Stunt.io[67] was added because it is a virtual world engine displaying web pages similar to Facebook. And (XXVI) the Internet[28] as a whole must be considered. Some technologies were eventually dropped from the results table, for example, a telephone call and Diablo), because their resulting classification was identical to others in the study.

**A Note on Scripting** Some of the technologies in the study have scripting languages available for extending them, (e.g., IRC, MUD). Given a sufficiently rich scripting language, it might prove impossible to determine the limits of their capabilities. Scripting is one technique through which a technology can be repurposed beyond its intended use,[26] for example, if a web server is enhanced with scripting to serve as a game server, is it still just a web server? In the study, technologies are considered without what is ultimately implementable if their scripting language was to be employed.

## A.1 Virtual (Simulated) Environment

All technologies listed in Table 1, except for the calculator, implement some form of VE. A calculator is a digital technology that simulates calculation on a digital display; the abstraction is not high enough to be considered implementing a VE.

## A.2 Shared Temporality (1T)

In email chess, players do not necessarily have to share any of the mentioned temporalities (real-world (R), hardware (H), simulated (S or ST), or virtual (V or VT)), but can maximally share real world time and ST; players play on different computers, with no VT implemented, only turn taking. The digital hardware of a calculator lacks both ST and VT. Because such a calculator is operated by just a single person, that person shares real-world and hardware time, with themselves and the calculator. CAD software, loaded with a CAD drawing, runs according to ST, for example, the CAD software can rotate the drawing according to certain clock speeds. If the CAD drawing contains animation, then subjective time and an epoch of zero to the start of the animation can be part of the loaded state, that is, support for VT. GDocs only uses real world time and ST; actions are translated into timed events that are synchronized on a cloud platform and disseminated to the various clients.

Skype is similar to a telephone call in the sense that participants share real-world time, but also records objective real-world times as ST, synchronizing these times to the

**TABLE A1**

| TECHNOLOGY | ST | VT | 1T | |
|---|---|---|---|---|
| email chess | ✓ | ✗ | - | ⊢RS |
| calculator | ✗ | ✗ | - | ⊢RH |
| CAD drawing | ✓ | ✗ | - | ⊢RHS |
| CAD/Maya animation | ✓ | ✓ | ✓ | ⊢RHSV |
| Google Docs | ✓ | ✗ | - | ⊢RS |
| Skype incl. video | ✓ | ✗ | - | ⊢RS |
| IRC | ✓ | ✗ | - | ⊢R[S] |
| Zork | ✓ | ✗ | - | ⊢RH[S] |
| Civ5, localhost | ✓ | ✓ | ✗ | ⊢RHS |
| Civ5, networked | ✓ | ✓ | ✓ | ⊢RSV |
| Civ5, single player | ✓ | ✓ | ✓ | ⊢RHSV |
| Civ5, email | ✓ | ✓ | ✗ | ⊢RS |
| Doom (Deathmatch) | ✓ | ✓ | ✓ | ⊢RHSV(RSV) |
| League of Legends | ✓ | ✓ | ✓ | ⊢RSV |
| MUD, localhost | ✓ | ✓ | ✓ | ⊢RHSV |
| MUD | ✓ | ✓ | ✓ | ⊢RSV |
| WoW, ONE shard | ✓ | ✓ | ✓ | ⊢RSV |
| WoW, all shards | ✓ | ✓ | ✗ | ⊢RS[V+] |
| Facebook | ✓ | ✗ | - | ⊢RS |
| the Internet | ✓ | ✓ | ✗ | ⊢R[SV+] |

different Skype clients; `VT` is not supported. Although the IRC protocol does, have a call to query another system's `ST` (marked `[S]` in the last column of Table A1), the IRC chat protocol[60] is an ordered list of events that is irrelevant of time, as long as they are kept sequentially intact. IRC does not implement `VT`, only real-world time is shared.

Although Zork has potential access to `ST` (`[S]`), it is a player's actions that progress the game state. This lacking is apparent in Zork not supporting `SA`. Civ5 is a turn-based game that can be played against a human or Artificial Intelligence (AI) agent. When played on a localhost (in Hotseat mode), players share real world, hardware, and `ST`. They do not, however, share `VT`; each player plays a time slot of `VT` and then passes control to the other player. If played through a network (over LAN or via a dedicated server), players no longer share hardware time, but they do share `ST` and `VT` in principle, that is, the player is playing, but just not allowed to make any actions (the `Rt` property will account for the lack of actions). In a single player game, when playing against an AI agent, the game behaves similarly; the player is playing, but not allowed to make any actions during the AI agents turn. It is also possible to play Civ5 over email, meaning Civ5 inherits the same `1T` aspects as email, that is, maximally sharing real world and `ST`,[68] even though `VT` is implemented. Doom supports `VT` because the game state can be frozen, saved, and loaded. Doom and MUD share all temporalities in single player localhost mode. Doom in multiplayer (max four) "Deathmatch" mode, LoL, MUD (when played through a network), and WoW share all temporalities except for hardware temporality. In WoW, there is a reference to real-world time in-game and some in-game effects are related to real-world time, for example, the day or night schedule. When considering all the shards of WoW (see ONE Shard), not one, many `VT`s are supported; it is assumed that only one `ST` is synchronized across all WoW servers.

Facebook is equal to Skype, with shared real-world time and a `ST` across cloud computing. The Internet is not one system such as Facebook, but many, supporting many `ST`s and `VT`s (each system on the Internet potentially having its own synchronized clock, plus abstractions); not all agents share the same `VT`, because there are MANY (+).

## A.3 Real time (`Rt`)

The real-time property only serves to classify turn-based technologies, such as email chess and Civ5. The Internet in its entirely includes email and so can not be considered a real-time system.

## A.4 Shared Spatiality (`1S`)

It can be argued that players control the pieces on the email chess board in a space supporting spatial properties, that is, supporting an allegory of space (`VS`). Players of email chess share `VS`, supporing `1S`.

Each digital digit on the display of a calculator is set in the display space, but the calculator does not simulate an allegory of physical space. CAD drawings are often models of the physical world, and so do support `VS`. A CAD drawing is a single user environment, so `VS` is shared with the user and the other entities in the space. GDocs might do a great job implementing an allegory of a sheet of paper, but not of physical space. For a calculator and GDocs, a representation of the user is not contained within the space.

Skype offers chat and also supports video: the chat does not provide `VS` on the same grounds that GDocs does not. Actual physical space is portrayed in video, but participants are viewing other participants moving through physical space (which is not modeled, see VE), rather than virtual space.

Zork and MUD are peculiar, because they do implement `VS`, but without a visualization of space; the allegory of space comes from the text description of each room[69[p.81]], player movement, and topology. A MUD with one room would be the equivalent to a chat service. When compared to MUD, it can be argued that IRC also allows a user to move between "channels" using text commands. However, IRC still lacks an allegory of physical space, which MUD provides through narrative.

The `1S` of Zork is based on a single user environment, like a CAD drawing. `VS` is supported by Civ5, Doom, LoL, and WoW; they have an allegory of physical space with the like-

**TABLE A2**

| TECHNOLOGY | VS | 1S | 1Sh |
|---|---|---|---|
| email chess | ✓ | ✓ | ✓ |
| calculator | ✗ | - | ✓ |
| CAD drawing | ✓ | ✓ | ✓ |
| Google Docs | ✗ | - | ✓ |
| Skype incl. video | ✗ | - | ✓ |
| IRC | ✗ | - | ✗ |
| Zork | ✓ | ✓ | ✓ |
| Civ5 | ✓ | ✓ | ✓ |
| Doom (Deathmatch) | ✓ | ✓ | ✓ |
| League of Legends | ✓ | ✓ | ✓ |
| sim/MUD, ZERO players | ✓ | ✓ | ✓ |
| MUD, localhost | ✓ | ✓ | ✓ |
| MUD, ONE room | ✗ | - | ✓ |
| MUD | ✓ | ✓ | ✓ |
| WoW, ONE shard | ✓ | ✓ | ✓ |
| WoW, all shards | ✓ | - | ✗ |
| Big World (regions, dynamic) | ✓ | ✓ | ✓ |
| EVE Online (regions, static) | ✓ | ✓ | ✓ |
| Facebook | ✗ | - | ✓ |
| Stunt.io | ✗ | - | ✓ |
| the Internet | ✓ | - | ✗ |

ness of a Euclidean 3D space. Civ5, Doom, LoL, MUD (with multiple rooms) and a single shard of WoW, support `1S`.

Facebook does not implement `VS` on the same grounds that GDocs does not. To complicate matters, Stunt.io[67] is a virtual world engine that acts as a web server; it does fail to provide `VS` if it just displays static web pages. If the entire Internet is considered, `VS` will be implemented somewhere.

## A.5 ONE Shard (`1Sh`)

In email chess, the game state consists of one or more data spaces spread out on one or more computers holding the email; the game state, however, is `1Sh`. When players email their moves to the other player(s), the game state is synchronized so that the next move can be made. The calculator, CAD drawing and Zork only have one data space and so are `1Sh`. GDocs and Facebook[70] are powered by cloud computing; many computers, each with their own data space that are synchronized to form the state of one document, news feed, profile, etc.

Skype, Civ5, Doom, and MUD can be considered similar to email chess, that is, partial state held in potentially more than one data space that is synchronized to form `1Sh`. IRC is chat service that spans multiple servers, with groups of servers supporting MANY IRC networks[71]; each IRC network can be considered a different shard.

Although all are video games, LoL is very different than Civ5 and Doom, in how their data spaces are set up. LoL has a networked virtual "lobby" where players gather, that want to play a game against each other. When a group of players has been formed, they enter a data space separated from other players. When the game is over, they are returned to the lobby. According to Section 5.1.2, each game is an instance similar to those of WoW. When results of each game are synchronized with the player profiles and leaderboards in the global data space, one `1Sh` is formed.

WoW is pronounced to be divided into a number of shards (called realms), each with various zones and land masses (mini worlds). There are many data spaces in WoW, but each "realm" is `1Sh` served by a single server; the entirety of WoW, all shards considered, is multiple shards. WoW has a feature where a group of players can play an instance dungeon; a data space where only the designated group of players are playing together, similar to a single game of LoL. When the instance dungeon is over, results of the instance dungeon are synchronized with the shard. In recent years, upgrades to WoW have allowed players from different shards to play in the same instance dungeon together; results from the instance dungeon are synchronized with each respective shard, but shards do not synchronize. BigWorld is `1Sh`, but contrary to WoW, space is dynamically regionalized. EVE Online is `1Sh` that is statically regionalized; one (SOL) server per solar system[72].

Similar to the entirety of WoW, all shards considered, the Internet is multiple shards. To access the Internet, a user uses a browser to connect to any number of different shards, by typing in an address.

## A.6 Size

Text-based MUDs have considerably less movement space than some modern worlds but were virtual worlds nonetheless; movement speeds have been set so that it takes tens of minutes to run through Doom or fly through WoW. In Doom, the player is teleported from one "level"[37][p. 693] to the next and teleporters also exist within a single level. Within one shard of WoW, there are mini worlds (called islands or planets, according to narrative) and a player can travel continuously across one mini world but must teleport between mini worlds. As with Doom, teleporters exist in WoW within mini world.

## A.7 Indoor or Outdoor

The setting for Doom is various levels set in factory-like complexes, with occasional areas where the player is let "outdoors." However, outdoors is a box that restrains the player's movement, but in a way that is believable with respect to the game. A level is set within a "sky box,"[37] which is superimposed with an image of an outdoor skyline. A sky box is usually the outermost box in the environment; beyond the sky box aspects of the environment are usually undefined. MUD has a room defined for each point a player can move to. Indoor and outdoor is a matter of narrative. If the player were to be able to escape the room structure of MUD, the area would be undefined. The graphical backdrop of WoW makes it mostly an outdoor experience, with some buildings in cities and dungeons being depicted as indoor experiences. In WoW, areas have either an edge that limits player movement or an area that is detrimental to the player (e.g., avatar death), stimulating them to backtrack.

## A.8 MANY Human Agents (`HA`)

All technologies support ONE human agent (`1H`), except for a pure simulation of a world. Email chess is usually played by two or more (`2+H`), but you can email yourself. A calculator, CAD drawing, and Zork were designed to support a `1H`. GDocs supports `HA`, with a maximum of 50 simultaneous users.[73] Skype and IRC conversations are often between two people, but can be a conference with multiple. Civ5 and Doom were designed with a single and multiplayer mode, supporting `HA`; Doom has a campaign in which only single player is supported and also a networked Deathmatch competitive mode for up to four players. LoL supports `HA` in a single game, but supports a more massive amount of players being connected to their servers simultaneously in the lobby.

**TABLE A3**

| TECHNOLOGY | 1H | 2+H | HA |
|---|---|---|---|
| email chess | ✓ | ✓ | ✓ |
| Zork | ✓ | ✗ | ✓ |
| sim/MUD, ZERO players | ✗ | ✗ | ✗ |
| MUD, localhost | ✓ | ✗ | ✓ |

MUD supports `HA`, for example, active MUDs often have hundreds of simultaneous players on one server. If MUD is used without networking, then it allows for ONE local player to be active.[19]

WoW supports massive amounts of players, with players spread over multiple shards. Facebook deals with massive amounts of users and is a website on the Internet, that is, the Internet also supports `HA`.

## A.9 MANY Software Agents (`SA`)

Email chess, a calculator, a CAD drawing (without animation), GDocs, Skype, IRC, Zork, and Facebook all do not support `VT`, that is, fail to support `SA`. A CAD drawing with animation supports `VT`, but does not implement `SA`. IRC supports bots that automate channel maintenance, but these are not agents; they only react to incoming messages and do not exhibit continuous behavior. In version 3.2B of Zork[42] there is a troll located in the cellar; it is not an agent, but equal to that of an IRC bot. Civ5, Doom, LoL, MUD, and WoW all support `SA`. Because Stunt.io is a virtual world engine, it does support `SA`. The Internet as a whole can not be discounted of `SA`, that is, somewhere on the Internet software agents will exist.

## A.10 Virtual Interaction (`Ix`)

Email chess, a calculator, a CAD drawing with and without animation, GDocs, Skype, IRC, Zork, and Facebook do not support `SA`, that is, fail to support `Ix`. Some of these (e.g., Facebook) allow for `Ix` between `HA` (e.g., communication tools), but without `SA`, human agents cannot have `Ix` with the world, only act on it. All the remaining technologies named in this subsection allow for `Ix` with people and action or reaction with things and the environment. In Civ5, players are confronted with artificial opponents and must have `Ix` with their units. The monsters in Doom take prescribed actions against the player allowing for `Ix`. Players of LoL have `Ix` with the other players, but the majority of units, which can be interacted with, are controlled by the game. MUD and WoW have entities with scripted behaviors. If all of WoW and the Internet is considered, the prerequisite of `1Sh` is not met. Facebook lacks the prerequisite of `SA`. Stunt.io serves web pages and does support `SA`. If no web interface is built such that the `SA` can take action on the user without it

**TABLE A4**

| TECHNOLOGY | 1Sh | SA | Ix |
|---|---|---|---|
| CAD/Maya animation | ✓ | ✗ | - |
| sim/MUD, ZERO players | ✓ | ✓ | ✓ |
| WoW, ONE shard | ✓ | ✓ | ✓ |
| WoW, all shards | ✗ | ✓ | - |
| Facebook | ✓ | - | - |
| Stunt.io | ✓ | ✓ | ✓ |

being a reaction, then Stunt.io falls in the same category as a pure simulation of a world, where `SA` only have `Ix` with each other.

## A.11 non-Pausable (`nZ`)

Email chess, Civ5 and the Internet fail to meet the `Rt` prerequisite. A calculator, GDocs, Skype, IRC, Zork, and Facebook are all `nZ`. A CAD drawing with animation can be paused, failing `nZ`. Doom supports `VT`, but can be paused in both single player and Deathmatch multiplayer mode. LoL supports pausing of the game, but only in tournament play (marked as positive for the benefit of the doubt). MUD and WoW both support `VT` and are `nZ`; if all the shards of WoW are taken into account, they collectively fail `1T`, but still support `nZ`.

## A.12 Persistence (`P`, world (`wP`), data (`dP`)) and Pseudo-

Email chess is a persistent technology, with both `dP` and ($\wedge$) `wP`; `dP` is provided for by the email server and loading email is just as persistent as loading the world of WoW. A calculator has no support for `dP` and so also fails `wP`. GDocs, Skype, and IRC are persistent technologies. IRC defeats the `dP` criterion by not having much data to persist; there is no real-world data beyond the preservation of some nicknames conversations are ephemeral.

Doom does support `dP`; it is possible to persist data, albeit manually. If Doom were left running to support `wP`, it would fail `dP`, if no one was around to save the state manually.[17] So it must fail either `wP` exclusively or ($\vee$) `dP`. The persistence of a CAD drawing, Zork, Civ5, and Diablo in single player is equal to that of Doom.

For multiplayer Diablo, player(s) are first gathered in a virtual lobby, before venturing into dungeons. Each dungeon is similar to an instance dungeon of WoW, where the dungeon is created for one run through it and reset. Afterwards, player data is preserved and the player(s) can choose to start another dungeon. Instances fail `wP`, but the virtual lobby is a persistent technology (the virtual lobby does fail other properties, for example, `VS` or `SA`). Because world data can be injected into an instance and results gathered from it, Diablo multiplayer is an example of pseudo persistence. Pseudo persistence can

account for statements like: "I think the persistance [*sic*] of the avatar is more important than the persistance [*sic*] of the world. Hence, Diablo is a VW, while Starcraft is not."[2[#18]] The persistence of LoL is equal to that of Diablo.

Bartle cocreated MUD, and so it is assumed that his criteria was based on his own experiences with MUD, that is, MUD passes his own criteria. MUD can be accessed through networking, but it is possible to access a MUD from a local machine as a single player game[19]; under this condition, MUD is similar to Doom in the sense that if the game or the system is turned off, the world fails to exist.[17] The difference being that, if MUD is left on for $wP$, the world data is still persisted to storage periodically, supporting $dP$.

A type of MUD, that has been referred to as a Groundhog Day MUD,[41] is one where the entire world is reset periodically. Such a world would be equal to that of Diablo (i.e., lacking $wP$), unless something in the world has been under the constant influence of the world's time, in which case $wP$ and $dP$ would be required for that something.[17]

WoW supports both $wP$ and $dP$, except for instance dungeons (similar to the games of LoL), but which are synchronized to the shard.

Facebook supports $wP$ and $dP$ for user data. Community oriented data can be considered world data and is also persisted, that is, Facebook is a persistent technology. The Internet, as a whole, satisfies Bartle's criterion for $wP$. Property $dP$ for all parts of the Internet is problematic (e.g., failing servers and services); $dP$ is marked as positive for the benefit of the doubt.

## A.13 MANY Avatar ($Av$)

A calculator and a CAD drawing do not support $Av$. GDocs uses a 2D image to represent the presence of a user in a shared document, with an indicator in the document to show where they are and which changes to the document they are making, that is, GDocs can not be discounted for supporting $Av$. Skype makes use of a 2D image on a profile and in chat to represent the user. Interaction via chat is similar to that of MUD, but with text and other media shown to be emanating from a user's image icon. Skype can be said to support $Av$, on the same grounds that MUD does. IRC is similar to MUD (and Skype), and so is marked as supporting text-based $Av$. Although similar to MUD, determining if Zork makes use of an avatar is more problematic. Zork is single player, with an ego-referenced viewpoint in the sense that the player can not see themselves and a third-person perspective can not be used to see if the player has an avatar. But the player has an entity in the game, with an inventory, that interacts with the fictional world and that is referred to as "you" in the game, for example, "The thief attacks, and you fall back desperately." On the basis of interaction, the conclusion is that Zork supports $Av$. If pieces on a chess board are considered under the control of the player, players of both email chess and Civ5 control multiple entities. The question is whether those entities are avatars; it can be argued that those entities are just pieces on a game board with abilities and the player has no avatar. On the grounds that a player should identify with their virtual selves (a personification if you will), those entities are discounted from being avatars. In Civ5, each player must also select to play a famous world leader, which does satisfy $Av$. Email chess is marked as not supporting $Av$ and Civ5 as supporting. In a single player game of Doom, the player has an ego-referenced viewpoint, with an entity $SA$ can interact with, that is, support for $Av$. In Deathmatch mode, Doom makes use of 2D images (simulating 3D models) as entity representations for player opponents. MUD uses text-based $Av$, while LoL and WoW both use a 3D model as $Av$. According to Bell and Robbins-Bell,[8] a Facebook profile explicitly does not qualify as an avatar, because of lack of agency. But since all interaction with other agents is done through the user profile, Facebook is considered to support $Av$ here. On the Internet as a whole, a user has many different representations, that is, not one unique avatar, but MANY; avatars are usually isolated to a particular shard.