

# Supplemental Material: Trend Analysis Data

## A. Mulsemmedia Rendering Devices

Table 1 contains a list of rendering devices, categorized by function and type and sorted in release year. Note that the following list of devices is by no means exhaustive to provide various rendering function.

Table 1. List of Mulsemmedia Rendering devices.

Product	Year	Sensation Type	Notation
<b>Glove</b>			
GloveOne <sup>6</sup>	2014	Vibrotactile feedback	
Mood Glove <sup>1</sup>	2016	Vibrotactile feedback	
Senso Glove <sup>2</sup>	2016	Haptic display	Include vibration and temperature fluctuation
Manus VR <sup>5</sup>	2016	Vibrotactile feedback	
Avatar VR <sup>7</sup>	2017	Vibrotactile feedback	
Hi5 VR Glove <sup>3</sup>	2018	Vibrotactile feedback	
Plexus <sup>4</sup>	2018	Vibrotactile feedback	
Cyteract <sup>9</sup>	2018	Force feedback	
Hands Omni <sup>8</sup>	Under development	Force feedback	
<b>Exoskeleton</b>			
Dexmo <sup>10</sup>	2016	Force feedback	
HGlove <sup>11</sup>	2017	Force feedback	
HaptX <sup>12</sup>	2017	Haptic display	Include realistic touch and force feedback
VRgluv <sup>13</sup>	2017	Force feedback	
SenseGlove <sup>14</sup>	2018	Force feedback	
CyberGlove <sup>15</sup>	2009	Force feedback	
<b>Thimble</b>			
VRTouch <sup>16</sup>	2017	Force feedback	
Tactai Touch <sup>17</sup>	2017	Force feedback	
<b>Chair</b>			
Emoti-chair <sup>19</sup>	2009	Haptic display	
MMOne VR Chair <sup>21</sup>	2015	Haptic display	
Telepod <sup>22</sup>	2016	Vibrotactile	
Roto VR Chair <sup>18</sup>	2017	Haptic display	Provide sense of weightlessness
Voyage <sup>20</sup>	2017	Haptic display	Provide sense of weightlessness
Yaw VR Motion Simulator <sup>23</sup>	2018	Haptic display	Include locomotion and vibrotactile
Feel Three <sup>24</sup>	Under development	Haptic display	Include locomotion and vibrotactile
<b>Vest</b>			
Interactor Vest <sup>26</sup>	1994	Vibrotactile feedback	
3RD Space Vest <sup>27</sup>	2007	Vibrotactile feedback	
Tactile Gaming Vest <sup>28</sup>	2010	Vibrotactile feedback	
ARAIG <sup>29</sup>	2013	Vibrotactile feedback	
KOR-FX <sup>30</sup>	2014	Vibrotactile feedback	
HAPTIKA <sup>32</sup>	2016	Vibrotactile feedback	
Rapture Vest <sup>33</sup>	2016	Vibrotactile feedback	
Synesthesia Suit <sup>25</sup>	2016	Vibrotactile feedback	Functioned as interactive skin

Product	Year	Sensation Type	Notation
Teslasuit DK1 <sup>31</sup>	2017	Vibrotactile feedback	
NullSpace VR <sup>34</sup>	2017	Vibrotactile feedback	
bHaptics TactSuit <sup>35</sup>	2017	Vibrotactile feedback	
Woojer ryg <sup>36</sup>	2017	Vibrotactile feedback	
NeoSensory Exoskin <sup>37</sup>	2018	Vibrotactile feedback	
<b>Fan</b>			
VirWind <sup>39</sup>	2015	Non-contact haptic display	Implemented through air blowing
ZephVR <sup>38</sup>	2017	Non-contact haptic display	Implemented through air blowing
The Ambiotherm <sup>41</sup>	2017	Non-contact haptic display	Implemented through air blowing and temperature change
VortX <sup>40</sup>	2018	Non-contact haptic display	Implemented through air blowing blow
Wind-Blaster <sup>42</sup>	2018	Non-contact haptic display	Implemented through air blowing
<b>Other Haptic Device</b>			
Novint Falcon <sup>43</sup>	2007	Force feedback	
Aireal <sup>44</sup>	2013	Non-contact haptic display	Implemented through airflow
AirWave <sup>45</sup>	2013	Non-contact haptic display	Implemented through airflow
<b>Olfactory Devices</b>			
Smell-O-Vision <sup>48</sup>	1959	Olfactory display	
AromaRama <sup>48</sup>	1959	Olfactory display	
iSmell <sup>48</sup>	1999	Olfactory display	
Pinoke <sup>48</sup>	2000	Olfactory display	
Scent Dome <sup>48</sup>	2003	Olfactory display	
Kaori Web <sup>48</sup>	2004	Olfactory display	
Aroma Generator <sup>48</sup>	2005	Olfactory display	
Aroma Shooter <sup>46</sup>	2012	Olfactory display	
Smelling Screen <sup>47</sup>	2013	Olfactory display	
Olorama <sup>50</sup>	2013	Olfactory display	
Scentasia <sup>51</sup>	2013	Olfactory display	
Aroma Shooter Mini <sup>52</sup>	2016	Olfactory display	
Nosulus Rift <sup>53</sup>	2016	Olfactory display	
Scentcom <sup>49</sup>	2017	Olfactory display	
OhRoma <sup>54</sup>	2017	Olfactory display	
<b>Gustatory Device</b>			
Meta Cookie <sup>56</sup>	2010	Gustatory display	
Digital Lollipop <sup>58</sup>	2013	Gustatory display	
Planet Licker <sup>55</sup>	2016	Gustatory display	
Vocktail <sup>57</sup>	2017	Gustatory display	
Virtual Lemonade <sup>59</sup>	2017	Gustatory display	
TastyFloats <sup>60</sup>	2017	Gustatory display	
Thermal Taste Machine <sup>61</sup>	2018	Gustatory display	
<b>Multisensory Device</b>			
Feelreal Sensory Mask <sup>63</sup>	2015	Contact haptic display Non-contact haptic display Olfactory display	Contact haptic display include: water mist, vibrotactile feedback,  Non-contact haptic display includes: wind display, thermal display
Virtual Cocoon <sup>62</sup>	Under Development	Haptic display, Olfactory display, Gustatory display	

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## B. Artificial Intelligence in Video Games

Table 2 contains a list of game intelligence systems and techniques, sorted in release year. Note that the following list of games is by no means exhaustive to cover all the type of artificial games. Moreover, the selection mainly includes the games with virtual world features, i.e., players incarnated by avatars. Thus, artificial intelligent techniques in other genres, such as real-time strategy and board game, are not included.

Table 2. List of game intelligence systems or techniques.

Game	Year	Genre	System or technique	Description
Space Invaders <sup>1</sup>	1978	Arcade	Stored pattern	Simulating random movements of the aliens that were actually pre-programmed into the game.
Pac-Man <sup>1</sup>	1980	Arcade	Complex Stored pattern	Different colorful enemies exhibit different personality traits
Rogue <sup>17</sup>	1980	Role-playing	PCG on game space	Provide changing play experiment with dynamic game environment generation.
Metal Gear <sup>3</sup>	1987	Action-adventure	Artificial behavior	NPCs are capable of hearing player movement, noticing gunshots, and behaving based on a lot more variables
Mortal Kombat <sup>1</sup>	1992	Fighting	FSM	Prompt enemy action in each single state
Civilization II <sup>4,5</sup>	1996	Turn-based strategy	MCST	To create a competitive opponent
Creatures <sup>11</sup>	1996	Life Simulation	Artificial life model, Neural network	Simulate real life functions, such a mutation and decision making
Half-Life <sup>3</sup>	1998	First-person shooter	FSM, Squad AI	Enable members of a squad of NPCs to coordinate their behaviors, allowing them to see their colleagues and notice if they are killed through sense simulation
The Sims <sup>1</sup>	2000	Simulation	Artificial life, Terrain analysis	Create realistic, lifelike behaviors in game characters with rule-based system, genetic algorithms, flocking algorithms, and decision-making hierarchy;  Make the pathfinding problem more flexible and location-based
Halo <sup>3</sup>	2001	First-person shooter	Decision-tree, Squad AI	Decision-tree creates dynamic enemy behaviors, such as cover-based behavior
Black and White <sup>6</sup>	2001	Simulation	Belief-desire-intention model, Decision tree, Perceptron neural network	For sophisticate task selection
EVE Online <sup>17</sup>	2003	MMORPG	PCG on game system	Create the entire solar system
.kkrieger <sup>17</sup>	2004	First-person shooter	PCG on game bits	Create texture, meshes, and sounds
Halo 2 <sup>7</sup>	2004	First-person shooter	Behavior tree	It is a hierarchical finite state machine to create complex tasks for control in different granularity
F.E.A.R. <sup>3</sup>	2005	First-person shooter	GOAP	The architecture is for NPC to extremely varied behavior that was perceived as intelligent, and to adapt to new situations.

Façade <sup>15</sup>	2005	Interactive drama	Computational narrative	Through artificial intelligence to bring interactive storytelling experience
Diablo II <sup>17</sup>	2008	Action-adventure	PCG on game scenarios	Create quests
GTA4 <sup>3</sup>	2008	Action-adventure	Emotion-response, Squad AI, Decision-tree	Emotion-response enable NPCs to react in a realistic way
Left 4 Dead <sup>13,16</sup>	2008	First-person shooter	AI Director, Pathfinding	A PCG mechanism to provide players a dynamic experience based on their performance;  A* algorithm is applied to move NPCs to a certain location
Killzone 2 <sup>8</sup>	2009	First-person shooter	HTN planning, Squad AI	NTN planning is based on visual perception to create believable NPCs,
Silent Hill: Shattered Memories <sup>9</sup>	2009	Survival horror	Psychological profiling	A PCG mechanism to adjust gameplay elements based on the player's personality determined by the interaction with the game
Heavy Rain <sup>15</sup>	2010	Interactive drama	Computational narrative, Virtual camera	Improve immersion in storytelling
The Elder Scrolls V: Skyrim <sup>14</sup>	2011	Open world	Radiant AI	Allow NPCs to dynamically react to and interact with the world
Hitman: Absolution <sup>10</sup>	2012	Action-adventure	Reinforcement learning	For animation to generate realistic locomotion for NPC crowd
République <sup>12</sup>	2012	Action-adventure	Tactical Pathfinding, GOAP, Point of interest (POI)	POI allows NPCs to randomly utilize the nearby items to create great variety behaviors
GTA5 <sup>1,2</sup>	2013	Action-adventure	Pathfinding, Artificial life, NPC-to-NPC interaction, Computer vision	Computer vision is applied to learn distance to stop signs in a race
The Last of Us <sup>3</sup>	2013	Action-adventure	Companion AI	For NPC to coordinate with player character.
Alien: Isolation	2014	Survival horror	Adaptive behavior	NPC behavior is adapted with each decision made by players
Forza Horizon 2 <sup>3</sup>	2014	Open world	Drivatar system	Use Neural networks to learn about driving of each player of the game for emulation
Metal Gear Solid 5 <sup>1</sup>	2015	Open world	Smart opponent	NPC can hunt players, improve health levels, reload ammo or seek cover during battle
No Man's Sky <sup>18</sup>	2016	Open world	Extreme PCG	Everything in the world is procedurally-generated

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## C. Full List of Sample Virtual Worlds

The following table lists 180 virtual world products in the market. This list focuses on the identifying virtual world architectures their scalability. This is by no means an exhaustive list. But it covers all typical architectures which are used in all past, current, and developing virtual worlds.

All samples are classified into: game worlds, social worlds, and child's worlds. The proportion of different classes of virtual worlds can truly reflect their respective proportion in the market, as investigated.

Most virtual worlds are investigated through the experience of play. A few virtual worlds have already been out of operation. For those virtual worlds which cannot be directly investigated through play, their architectures are explored by watching user replays on Youtube, reading official game Wikipedia, and collecting the traces from news and forums.

In summary, 6 types of scalability approaches are discovered:

- 1) Shard,
- 2) Shard + Zone + Instance,
- 3) Shard + Instance,
- 4) Zone,
- 5) Instance,

Some virtual worlds of the same type may show slight differences. For example, RuneScape and Wizard101 allow users to freely switch accounts among several shards, while other sharded worlds do not allow it. The description of each type and differences are detailed in the Description field.

The data of Peak User Base are also collected from various sources. The values in this column are only reported peak values during the operation of worlds. Due to different virtual world types, consumption models (fix fee change, monthly subscription, pay-as-you-go, and free-to-play), and business considerations, user bases of different virtual worlds are disclosed in different ways by their respective operators:

- 1) Created Accounts (CA) – active & in-active users of non-monthly subscribed virtual worlds,
- 2) Subscriptions (SS) – active users of monthly subscribed virtual worlds,
- 3) Active Accounts (AA) – active users of non-monthly subscribed virtual worlds,
- 4) Unique Visitor (UV) – active users & potential users of Web-page virtual worlds only,
- 5) Concurrent Users (CU) – active users of any virtual worlds, concurrently online.

As observed, some virtual worlds have only a few concurrent users online for a long period. This may result in wrongly identified architecture. If user population is low on a server, the way of scaling may be veiled (if it is not documented and released). For example, a non-zoning world might show zoning characteristic if a region were fully populated. It can be observed that all single-seamless worlds only have a very small number of concurrent users. Thus, they are too small to show their real scalability. The best index to validate the architecture of a virtual world is the number of concurrent users. Unfortunately, not all operators disclosed this figure.

Some collections of user population are divided into different regions, e.g., global, North America, and Korea. If the users of a virtual world are mainly from one region, e.g., Asian developed games mainly played by eastern users, only the data of that region is displayed. If the users are evenly distributed in different regions, the data from all regions are displayed, e.g., World of Warcraft. The values ended with (Steam) are the data collected from Steam DB, on Jan. 23, 2016.

Each virtual world links to its (global / regional) official Web site. Please be noted that the URL may change with the change of domain / sub-domain name, leading to access fail. For those virtual worlds out of operation, their landing page points to the Wikipedia page. Table 3

Table 4 List of Investigated Sample Virtual Worlds

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
<b>Game Worlds</b>					
1	<a href="#">Never Winter Nights (AOL)</a>	Shard	115,000 CA <sup>4</sup>	1991-01-01	The game world of Never Winter Night (AOL) is copied into several parallel servers. On each server, regions do not restrict the number of users. User accounts switching between servers are restricted. Instance system is not found.
2	<a href="#">Nexus: The Kingdom of the Winds</a>	Shard + Instance	12,263 CU in a single shard <sup>85</sup>	1996-01-01	Same as Asheron's Call
3	<a href="#">The Realm Online</a>	Shard + Instance	25,896 SS	1996-01-01	Same as Asheron's Call
4	<a href="#">Furcadia</a>		4500 CU	1996-12-16	Furcadia seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability.
5	<a href="#">Tibia</a>	Shard + Instance	113,299 SS; 64,000 CU	1997-01-07	Same as Asheron's Call
6	<a href="#">Ultima Online</a>	Shard	250,000 SS	1997-09-24	Same as Never Winter Nights
7	<a href="#">Underlight</a>		Few CU	1998-03-01	Underlight seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability.
8	<a href="#">Lineage</a>	Shard + Instance	3,000,000 SS	1998-10-03	Same as Asheron's Call
9	<a href="#">EverQuest</a>	Shard + Zone + Instance	550,000 SS	1999-03-16	The game world is copied into several parallel servers. On each server, each zone only allows limited number of users. Some zones are instanced.

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
10	<a href="#">Clan Lord</a>	Shard	100 CU	1999-10-18	Same as Never Winter Nights
11	<a href="#">Asheron's Call</a>	Shard + Instance	120,000SS	1999-11-02	Asheron's Call is run on several parallel shards. On each shard, the game maintains a seamless world with dynamic load balancing technology. It dynamically assigns computing load to different servers for each region according to the player population in that region. Some regions do not restrict the number of users, while others do but they are copied into many instances for different groups. User accounts switching between servers are restricted.
12	<a href="#">Aces High</a>	Instance		2000-05-08	Same as Guild Wars
13	<a href="#">RuneScape</a>	Shard + Instance	1,200,000 SS; 250,000 CU	2001-01-04	Same as Asheron's Call except that users are free to switch between all available servers.
14	<a href="#">Anarchy Online</a>	Shard + Instance	1,100,000 SS; 60,000 AA	2001-06-27	Same as Asheron's Call
15	<a href="#">Dark Age of Camelot</a>	Shard + Instance	250,000 SS	2001-10-09	Same as Asheron's Call
16	<a href="#">The Legend of Mir 2</a>	Shard + Instance	1,000,000 CU;	2001-10-19	Same as Asheron's Call
17	<a href="#">Final Fantasy XI</a>	Shard	550,000 SS	2002-05-16	Same as Never Winter Nights
18	<a href="#">Westward Journey Online II (大话西游 Online II)</a>	Shard + Instance	1,190,000 CU	2002-08-02	Same as Asheron's Call
19	<a href="#">Ragnarok Online</a>	Shard + Instance	750,000 CU	2002-08-31	Same as Asheron's Call
20	<a href="#">Ashen Empires</a>	Shard		2002-09-01	Same as Never Winter Nights
21	<a href="#">Neocron 2</a>	Shard + Instance	6,000 SS; Few CU	2002-09-09	Neocron 2 is supposed to be run on several servers in parallel. (Due to the small number of players for the time being, there is one serve, called Vedeena, for the time being.) Neocron dungeons are not instanced. Neocron uses only one instance zone, Area MC5. In other places, players can meet others.
22	<a href="#">Earth &amp; Beyond</a>	Shard	38,000 SS	2002-09-24	Same as Never Winter Nights
23	<a href="#">Asheron's Call 2</a>	Shard + Instance		2002-11-22	Same as Asheron's Call
24	<a href="#">EUDemons Online</a>	Shard + Instance	570,000 CU	2003-01-01	Same as Asheron's Call
25	<a href="#">Gekkeiju Online</a>	Shard + Instance		2003-01-01	Same as Asheron's Call
26	<a href="#">Entropia Universe</a>	Zone	500,000 CA <sup>29</sup>	2003-01-30	Same as EVE Online
27	<a href="#">A Tale in the Desert</a>	Shard	2,089 SS	2003-02-15	Same as Never Winter Nights
28	<a href="#">Shadowbane</a>	Shard	50,000 SS	2003-03-25	Same as Never Winter Nights



No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
29	<a href="#">MapleStory</a>	Shard + Instance	250,000 CU (Korea)	2003-04-29	
30	<a href="#">Eve Online</a>	Zone	500,000 SS	2003-05-06	Eve Online is run on single-server mode. In the game world, each zone only allows limited number of users. If a zone is full, newly coming users have to queue.
31	<a href="#">PlanetSide</a>	Shard	60,000 SS	2003-05-20	Same as Asheron's Call
32	<a href="#">Star War Galaxies</a>	Shard + Instance	300,000 SS	2003-06-25	Star War Galaxies is copied into several parallel servers. On each server, some regions do not restrict the number of users, while others do but they are copied into many instances for different groups.
33	<a href="#">World of Legend</a>	Shard + Instance	50,000 CU	2003-07-18	Same as Asheron's Call
34	<a href="#">Istaria: Chronicles of the Gifted</a>	Shard + Instance	36,000 SS	2003-09-09	Same as Asheron's Call
35	<a href="#">Lineage II</a>	Shard + Instance	2,000,000 SS; 14,000,000 CA <sup>87</sup>	2003-10-01	Same as Asheron's Call
36	<a href="#">MU Online (奇迹)</a>	Shard + Instance	400,000 CU	2003-10-06	Same as Asheron's Call
37	<a href="#">Puzzle Pirates</a>	Shard + Instance	4,000,000 CA <sup>35</sup>	2003-12-08	Same as Asheron's Call, multiplayer puzzles are instances to players in Puzzle Pirates
38	<a href="#">Fantasy Westward Journey (梦幻西游)</a>	Shard + Instance	1,000,000 CU <sup>80</sup> 1,330,000 CU <sup>81</sup> 1,500,000 CU <sup>30</sup> 2,320,000 CU <sup>83</sup> 2,560,000 CU <sup>84</sup> 2,600,000 CU <sup>77</sup>	2003-12-18	Same as Asheron's Call
39	<a href="#">Red Stone</a>	Shard + Instance		2004-01-01	Same as Asheron's Call
40	<a href="#">Ran Online</a>	Shard		2004-04-20	Same as Never Winter Nights
41	<a href="#">City of Heroes</a>	Shard + Instance	194,000 SS <sup>17</sup>	2004-04-27	Same as Asheron's Call
42	<a href="#">Mabinogi</a>	Shard + Instance	397,526 ± 13,681 CA (Steam); 1,229 CU (Steam)	2004-06-24	Same as Asheron's Call
43	<a href="#">The First Myth (封神榜 Online)</a>	Shard + Instance	203,480	2004-08-01	Same as Asheron's Call
44	<a href="#">Knight Online</a>	Shard + Instance	4,000,000 CA <sup>88</sup>	2004-08-17	Same as Asheron's Call
45	<a href="#">Dofus</a>	Shard + Instance	3,000,000 CA <sup>20</sup> ; 450,000 AA; 250,000 CU	2004-09-01	Same as Asheron's Call

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
46	<a href="#">Pardus</a>	Shard		2004-09-14	Same as Never Winter Nights
47	<a href="#">Ryzom</a>	Shard		2004-09-19	Same as Never Winter Nights
48	<a href="#">The Legend of Mir 3</a>	Shard + Instance	750,000 CU <sup>89</sup>	2004-10-01	Same as Asheron's Call
49	<a href="#">Uncharted Waters Online: Gran Atlas (大航海时代 Online)</a>	Shard + Instance	196,907 $\pm$ 9,632 CA (Steam); 462 CU (Steam)	2004-10-30	Same as Asheron's Call
50	<a href="#">Vendetta Online</a>		Few CU	2004-11-01	Vendetta Online seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability.
51	<a href="#">EverQuest II</a>	Shard + Instance	330,000 SS; 303,325 $\pm$ 12,128 SS (Steam)	2004-11-09	Same as Asheron's Call
52	<a href="#">Conquer Online (征服 Online)</a>	Shard + Instance	92,000 CU	2004-11-14	Same as Asheron's Call
53	<a href="#">World of Warcraft</a>	Shard + Instance	10,000,000 SS; 1,010,395 CU (West); 1,000,000 CU (East); 600,000 CU (China)	2004-11-23	Same as Asheron's Call
54	<a href="#">PlaneShift</a>	Shard		2004-12-24	Same as Never Winter Nights
55	<a href="#">The Matrix Online</a>	Shard	48,000 SS	2005-03-22	Same as Never Winter Nights
56	<a href="#">Zhen Feng Shen (真封神 Online)</a>	Shard + Instance	100,000 CU	2005-04-01	Same as Asheron's Call
57	<a href="#">Guild Wars</a>	Instance	6,000,000 CA <sup>5</sup>	2005-04-26	Guild Wars is not entirely run on multiple parallel shards. Instead, the world will assign each user a unique instance for play. Users can join others' instance to form groups, while group size is limited, except the hub zone (i.e., the town).
58	<a href="#">Shot-Online</a>	Shard + Instance		2005-06-28	Same as Fiesta Online
59	<a href="#">Dungeon and Fighter (地下城与勇士)</a>	Shard + Instance	2,600,000 CU <sup>78</sup> 3,000,000 CU <sup>79</sup>	2005-08	Same as Asheron's Call
60	<a href="#">Cabal Online</a>	Shard + Instance	480,000 CU <sup>16</sup>	2005-10-01	Same as Asheron's Call
61	<a href="#">Silkroad Online</a>	Shard	7,200,000 CA; 100,000 CU <sup>38</sup>	2005-10-01	Same as Never Winter Nights
62	<a href="#">Perfect World (完美世界)</a>	Shard + Instance	300,000 CU <sup>33</sup>	2005-11-25	Same as Asheron's Call
63	<a href="#">Minions of Mirth</a>	Instance		2005-12-01	Same as Guild Wars
64	<a href="#">Flyff</a>	Shard + Instance	30,000,000 CA	2005-12-25	Same as Asheron's Call

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
65	<a href="#">Ask Tao</a>	Shard + instance	1,010,000 CU	2006-01-01	Same as Asheron's Call
66	<a href="#">Hero Online</a>	Shard		2006-01-01	Same as Never Winter Nights
67	<a href="#">Granado Espada</a>	Shard + Instance	30,817 $\pm$ 3,812 CA (Steam); 265 CU (Steam)	2006-02-14	Same as Asheron's Call
68	<a href="#">RF Online</a>	Shard + Instance		2006-02-21	Same as Asheron's Call
69	<a href="#">Dungeons &amp; Dragons Online</a>	Shard + Instance	109,000 AA; 1,569,448 CA <sup>24</sup>	2006-02-28	Same as Asheron's Call
70	<a href="#">Dynasty Warriors Online (真·三国无双 Online)</a>	Shard + Instance		2006-03-01	Same as Asheron's Call
71	<a href="#">Auto Assault</a>	Shard + Instance	34,000 SS	2006-04-11	Same as Asheron's Call
72	<a href="#">Zhengtu (征途)</a>	Shard + Instance	2,000,000 CU	2006-04-21	Same as Asheron's Call
73	<a href="#">Shaiya</a>	Shard + Instance	520,000 CU	2006-06-18	Same as Asheron's Call
74	<a href="#">Scions of Fate (热血江湖)</a>	Shard + Instance	600,000 CU <sup>46</sup>	2006-11-13	Same as Asheron's Call
75	<a href="#">Dragon Oath (天龙八部)</a>	Shard + Instance	80,000 CU <sup>90</sup> ; 50,000,000 CA <sup>91</sup>	2007-01-01	Same as Asheron's Call
76	<a href="#">Vanguard: Saga of Heroes</a>	Shard + Instance	120,000 SS	2007-01-30	Same as Fiesta Online
77	<a href="#">Puppet Guardian</a>	Shard		2007-04-01	Same as Never Winter Nights
78	<a href="#">The Lord of the Rings Online</a>	Shard + Instance	564,000 SS	2007-04-24	Same as Asheron's Call
79	<a href="#">Champions of Regnum</a>	Shard + Instance	500,000 SS	2007-05-24	Same as Asheron's Call
80	<a href="#">Giant Online (巨人)</a>	Shard + Instance	344,005 CU	2007-06-15	Same as Asheron's Call
81	<a href="#">Empire of Sports</a>	Shard + Instance		2007-08-01	Same as Asheron's Call
82	<a href="#">Twelve Sky</a>	Shard + Instance		2007-10-12	Same as Asheron's Call
83	<a href="#">Fiesta Online</a>	Shard + Instance	270,545 $\pm$ 11,289 CA (North America, Steam); 117 CU (North America, Steam); 226,857 $\pm$ 10,338 (Global, Steam); 135 CU (Global, Steam)	2007-11-07	Fiesta Online is run on several parallel servers. On each server, the game opens an instance for each player. Players can also form group in dungeons (i.e., group instances)

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
84	<a href="#">Tabula Rasa</a>	Shard + Instance	125,000 SS	2007-12-02	In Tabula Rasa, there will be different 'versions' of each zone and each 'version' has a limited player capacity. When a version of the zone hits its player limit, a new version of the zone is created for any new players that enter.
85	<a href="#">Elsworld</a>	Shard + Instance	853,839 $\pm$ 20,034 CA (Steam); 50,000 CU <sup>28</sup> ; 1,834 CU (Steam)	2007-12-27	Same as Asheron's Call
86	<a href="#">Atlantica Online</a>	Shard + Instance	190,100 $\pm$ 9,465 CA (Steam); 52 CU (Steam)	2008-01-01	Same as Asheron's Call
87	<a href="#">Fragoria</a>	Shard + Instance		2008-01-01	Same as Asheron's Call
88	<a href="#">Pirates of the Burning Sea</a>	Shard + Instance	100,000 SS	2008-01-22	Same as Asheron's Call
89	<a href="#">R.O.H.A.N.: Blood Feud</a>	Shard + Instance		2008-03-28	Same as Asheron's Call
90	<a href="#">Wonderland Online</a>	Shard + Instance	50,000 – 60,000 CU <sup>45</sup>	2008-04-09	Same as Asheron's Call
91	<a href="#">Age of Conan: Hyborian Adventures</a>	Shard	159,000 SS <sup>10</sup>	2008-05-20	Same as Never Winter Nights
92	<a href="#">AdventureQuest Worlds (AQ Worlds)</a>	Shard + Zone	10,000,000 CA <sup>9</sup>	2008-06-02	The game world of AQ is copied into several parallel servers. On each server, each zone only allows limited number of users. Instance system is not found in this game.
93	<a href="#">Twelve Sky 2</a>	Shard + Instance	80,000 CU <sup>40</sup>	2008-07-18	Same as Asheron's Call
94	<a href="#">Dead Frontier</a>	Shard + Instance		2008-08-21	Same as Drakensang Online
95	<a href="#">Yu Yan 预言 (Online)</a>	Shard + Instance	380,000 CU	2008-08-28	Same as Asheron's Call
96	<a href="#">Warhammer Online</a>	Shard + Instance	800,000 SS	2008-09-18	Same as Asheron's Call
97	<a href="#">Parallel Kingdom</a>	Instance	1,000,000 CA	2008-11-04	Same as Guild Wars
98	<a href="#">Aion: The Tower of Eternity</a>	Shard + Instance	4,077,000 SS; 530,000 CU	2008-11-25	Same as Asheron's Call
99	<a href="#">Wizard101</a>	Shard + Instance	50,000,000 CA <sup>44</sup>	2008-12-02	Same as Asheron's Call except that shards (or realms and areas) are free to switch
100	<a href="#">AIKA Online</a>	Shard + Instance		2009-01-01	Same as Asheron's Call
101	<a href="#">Shou Xue Fei Teng (兽血沸腾)</a>	Shard + Instance	400,000 CU	2009-01-01	Same as Asheron's Call

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
102	<a href="#">Runes of Magic</a>	Shard + Instance	2,000,000 CA <sup>36</sup>	2009-03-19	Same as Asheron's Call
103	<a href="#">Requiem</a>	Shard + Instance	181,436 $\pm$ 9,246 CA (Steam); 305 CU (Steam)	2009-06-19	Same as Asheron's Call
104	<a href="#">Hello Kitty Online</a>	Shard	3,300,000 CA <sup>32</sup>	2009-07-01	Same as Never Winter Nights
105	<a href="#">Champions Online</a>	Instance	586,388 $\pm$ 16,610 CA (Steam); 986 CU (Steam)	2009-09-01	Same as Guild Wars
106	<a href="#">Fallen Earth</a>	Shard + Instance	1,612,133 $\pm$ 27,488 CA (Steam); 930 CU (Steam)	2009-09-22	Same as Asheron's Call
107	<a href="#">Journey to the West (西游记 Online)</a>	Shard + Instance	300,000 CU	2010-01-15	Same as Asheron's Call
108	<a href="#">Vindictus (Mabinogi Heroes)</a>	Shard + Instance	100,000 CU <sup>41</sup>	2010-01-21	Same as Fiesta Online
109	<a href="#">Star Trek Online</a>	Shard + Instance	14,800 AA	2010-02-02	Same as Asheron's Call
110	<a href="#">Dragonica</a>	Shard + Zone + Instance		2010-02-20	Same as EverQuest
111	<a href="#">Dragon Nest</a>	Shard + Zone + instance	200,000,000 CA <sup>21</sup> ; 900,000 CU <sup>22</sup>	2010-05-01	Same as EverQuest
112	<a href="#">Final Fantasy XIV</a>	Shard + Instance	800,000–1,200,000 SS <sup>8</sup>	2010-09-30	Same as Asheron's Call
113	<a href="#">Lego Universe</a>	Shard + Instance	90,000 SS	2010-10-26	Same as Asheron's Call
114	<a href="#">Perpetuum</a>	Zone	6016 SS	2010-11-25	Same as EVE Online
115	<a href="#">DC Universe Online</a>	Shard + Instance	18,000,000 SS <sup>19</sup>	2011-01-11	Same as Asheron's Call
116	<a href="#">TERA</a>	Shard + Instance	1,400,000 CA <sup>86</sup> ; 160,000 CU (Korea)	2011-01-25	Same as Asheron's Call
117	<a href="#">Battlestar Galactica Online</a>	Shard	10,000,000 CA <sup>13</sup>	2011-02-08	Same as Never Winter Nights
118	<a href="#">Rift</a>	Shard + Instance	600,000 SS	2011-03-01	Same as Asheron's Call
119	<a href="#">Xsyon</a>	Zoned		2011-03-15	Same as Wurm Online
120	<a href="#">Spiral Knights</a>	Instance	3,000,000 CA <sup>39</sup>	2011-04-04	Same as Guild Wars
121	<a href="#">Realm of the Mad God</a>	Shard	2,276,244 $\pm$ 32,621 CA (Steam); 2,831 CU (Steam)	2011-06-20	Same as Never Winter Nights

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
122	<a href="#">Drakensang Online</a>	Shard + Instance	3,000,000 CA <sup>18</sup>	2011-08-01	Drakensang Online is run on multiple parallel shards. On each shard, the game will assign each user a unique instance for play. Users can join others' instance to form groups, while group size is limited, except the hub zone.
123	<a href="#">9Dragons</a>	Shard + Instance		2011-09-17	Same as Asheron's Call
124	<a href="#">Digimon Masters</a>	Shard + Instance		2011-10-20	
125	<a href="#">Star Wars: The Old Republic</a>	Shard + Instance	1,700,000 SS	2011-12-03	Same as Asheron's Call
126	<a href="#">Wakfu</a>	Shard + Instance	916,834 $\pm$ 20,757 CA (Steam); 4,026 CU (Steam)	2012-02-29	Tactical turn-based MMORPG
127	<a href="#">Ragnarok Online 2</a>	Shard + Instance	1,047,652 $\pm$ 22,183 CA (Steam); 528 CU (Steam)	2012-03-26	Same as Asheron's Call
128	<a href="#">Phantasy Star Online 2</a>	Shard + Instance	3,500,000 CA <sup>34</sup>	2012-06-04	Same as Asheron's Call
129	<a href="#">Blade &amp; Soul</a>	Shard + Instance	1,000,000 AA <sup>15</sup>	2012-06-30	Same as Asheron's Call
130	<a href="#">The Secret World</a>	Shard + Instance	1,000,000 CA <sup>37</sup>	2012-07-03	Same as Asheron's Call
131	<a href="#">Dragon Quest X</a>	Shard + Instance	300,000 AA (Daily) <sup>23</sup>	2012-08-02	Same as Asheron's Call
132	<a href="#">Guild Wars 2</a>	Shard + Instance	3,000,000 CA <sup>6</sup> ; 400,000 CU <sup>7</sup>	2012-08-28	Same as Asheron's Call
133	<a href="#">Wurm Online</a>	Zone	18,936 $\pm$ 2,988 CA (Steam); 1,958 CU (Steam)	2012-12-12	Sandbox MMORPG; Each land in Wurm is run by one sever. All servers (i.e., lands) are connected, forming a complete map. The number of users on each land is limited.
134	<a href="#">ArcheAge</a>	Shard + Instance	17,332 SS <sup>12</sup>	2013-01-25	Sandbox MMORPG; Same as Asheron's Call
135	<a href="#">Marvel Heroes</a>	Instance	3,613,748 $\pm$ 40,996 CA (Steam); 8,759 CU (Steam)	2013-06-04	Same as Guild Wars
136	<a href="#">Neverwinter</a>	Shard + Instance		2013-06-20	Same as
137	<a href="#">Age of Wulin</a>	Shard + Instance	28,880,000 CA <sup>11</sup>	2013-07-18	Same as Asheron's Call
138	Defiance	Shard + Zone + Instance	2,851,741 $\pm$ 36,472 CA (Steam); 11,263 CU (Steam)	2013-08-02	Same as EverQuest, Story mode +multi-team
139	<a href="#">Darkfall Unholy Wars</a>	Shard + Instance		2013-08-16	Same as Asheron's Call
140	<a href="#">Echo of Soul</a>	Shard + Instance	433,541 $\pm$ 14,287 CA (Steam); 2,730 CU (Steam)	2013-09-11	Same as Asheron's Call

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
141	<a href="#">Aura Kingdom</a>	Shard + Instance	1,791,670 $\pm$ 29,393 CA (Steam); 2,165 CU (Steam)	2013-12-23	Same as Asheron's Call
142	<a href="#">Black Desert</a>	Shard + Instance	1,500,000 CA <sup>14</sup>	2014-01-01	Same as Asheron's Call
143	<a href="#">The Elder Scrolls Online</a>	Instance	772,374 SS <sup>25</sup>	2014-04-04	The Elder Scrolls Online adopts MeagServer technology <sup>26,27</sup> to realize dynamic switch between single and instance mode. When the player population is small, the game presents a single, seamless world. When some region servers are overloaded, copies of the region will be dynamically created and merged, with the fluctuation of player population.
144	<a href="#">WildStar</a>	Shard + Instance	40,000–50,000 CU <sup>42,43</sup>	2014-06-03	Same as Asheron's Call
145	<a href="#">Firefall</a>	Shard + Instance	2,686,023 $\pm$ 35,408 CA (Steam); 13,397 CU (Steam)	2014-07-29	Same as Asheron's Call
146	<a href="#">Elite: Dangerous</a>	Zone	694,297 $\pm$ 18,336 SS (Steam)	2014-12-16	Same as EVE Online
147	<a href="#">H1Z1</a>	Shard	2,151,748 CA <sup>31</sup>	2015-01-15	Same as Never Winter Nights
148	<a href="#">Trove</a>	Instance	4,604,593 $\pm$ 46,188 CA (Steam); 58,949 CU (Steam)	2015-07-09	Away from the hub, players in Trove will enter their own instanced world zones or join other's dungeon play. Clubs also have their respective Club world.
149	<a href="#">Shroud of the Avatar: Forsaken Virtues</a>	Instance		2016-01-01	Same as Guild Wars
<b>Social Worlds</b>					
150	<a href="#">Moove</a>	Zone	1,546,464 CA <sup>55</sup>	1994-01-01	Same as Asheron's Calltive Worlds
151	<a href="#">Active Worlds</a>	Zone	1,000,000 AA <sup>47</sup>	1995-06-28	In Active worlds, each world (i.e., a region) is run by a world server. The number of concurrent users a world can support depends on the capacity of that particular world server, mainly on CPU power, memory, and bandwidth. If a world is full of users, others must queue and wait.
152	<a href="#">Habbo Hotel</a>	Shard + Zone	178,000,000 CA; 15,000,000 UV <sup>48</sup> ; 100,000 CU <sup>49</sup>	2001-09-26	Habbo Hotel shards are geographically distributed all over the world. On each regional shard, the world is divided into many zones (i.e., rooms) which only allow limited number concurrent access.
153	<a href="#">WeeWorld</a>	Zone	60,000,000 CA <sup>65</sup> ; 2,100,000 UV (Monthly) <sup>66</sup>	2002-01-01	Same as Asheron's Calltive Worlds
154	<a href="#">The Sims Online</a>	Zone	105,000 SS	2002-12-17	Same as Asheron's Calltive Worlds
155	<a href="#">There</a>	Zone	170,000 AA	2003-01-09	Same as Asheron's Calltive Worlds
156	<a href="#">Second Life</a>	Zone	800,000 AA	2003-06-23	Same as Asheron's Calltive Worlds

No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
157	<a href="#">Kaneva</a>	Zone	5,000,000 CA; 300 CU <sup>53</sup>	2004-01-01	Same as Asheron's Calltive Worlds
158	<a href="#">IMUV</a>	Zone	20,000,000 CA <sup>56</sup> ; 800,000 AA (Monthly) <sup>57</sup>	2004-04-15	Same as Asheron's Calltive Worlds
159	<a href="#">Rise: The Vieno Province</a>		Few CU	2006-01-01	Rise seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability.
160	<a href="#">Utherverse</a>	Instance	1,500,000 CA <sup>59</sup>	2006-01-01	Same as Onverse
161	<a href="#">Meez</a>	Zone	3,000,000 UV (Monthly) <sup>54</sup>	2006-03-28	Same as Asheron's Calltive Worlds
162	<a href="#">vSide</a>	Zone	150,000 SS <sup>58</sup>	2006-05-15	Same as Asheron's Calltive Worlds
163	<a href="#">Onverse</a>	Instance	600,000 SS <sup>51</sup>	2007-06-15	Onverse' world is not entirely copied and run on multiple parallel shards. But each region of the world has multiple copies, in case a large number of users want to access to the same region.
164	<a href="#">SmallWorlds</a>	Zone	25,000,000 CA <sup>62</sup> ; 101,335 UV (Daily) <sup>63</sup>	2007-12-01	Same as Asheron's Calltive Worlds
165	<a href="#">Club Cooe</a>	Zone		2008-01-01	Same as Asheron's Calltive Worlds
166	<a href="#">Twinty</a>	Zone		2008-09-05	Same as Asheron's Calltive Worlds
167	<a href="#">Free Realms</a>	Shard + Instance	20,000,000 CA <sup>52</sup>	2009-04-28	Same as Asheron's Call
168	<a href="#">WoozWorld</a>	Zone	8,500,000 CA <sup>60</sup> ; 2,673,173 UV (Monthly) <sup>61</sup>	2010-01-01	Same as Asheron's Calltive Worlds
169	<a href="#">Chit Chat City</a>		Few CU; 22,610 UV (Daily) <sup>64</sup>	2010-01-01	Chit Chat City seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability.
170	<a href="#">Play-town Game</a>	Instance	Few CU	2014-01-20	Same as Onverse
171	<a href="#">Zanpo</a>		Few CU; 47 UV (Daily) <sup>67</sup>		Zanpo seems to be run on only one server with no restriction in each zone. But, the user population of this world is too small to show its scalability. Beside, no player interaction is designed.
172	<a href="#">OpenSim</a>	Zone	496,344 CA; 34,160 AA <sup>55</sup>	N.A.	OpenSim includes all public virtual worlds which are constructed with the OpenSim platform. On this platform, many virtual worlds are operated and connected to each other through Hypergrid protocol, including InWorldz, Kitley, OSGrid, etc.
<b>Child's Worlds</b>					
173	<a href="#">Whyville</a>	Zone + Instance	4,000,000 CA <sup>71</sup> ; 750,000 UV (Monthly) <sup>72</sup>	1999-02-01	Whyville is run only on one shard. The entire world is divided on many zones each of which limits the number of concurrent user access. Some rooms have multiple copies.



No.	Name	Scalability Approach	Population <sup>1,2,3</sup>	Release Date	Description on Architecture
174	<a href="#">Toontown Online</a>	Shard + Zone	110,000 AA	2003-06-02	The Toontown world is copied into several parallel servers. On each server, each zone only allows limited number of users.
175	<a href="#">Club Penguin</a>	Shard + Zone	200,000,000 CA <sup>68</sup>	2005-10-24	Same as Toontown Online
176	<a href="#">Roblox</a>	Instance	100,000 CU <sup>69</sup>	2006-01-01	Roblox is not run on multiple parallel shards. Each region of the world has multiple copies
177.	<a href="#">Space Heroes Universe!</a>		2,000,000 CA <sup>70</sup>	2007-01-01	Little Space Heroes is run only on one shard. The entire world is divided on many zones, each of which limits the number of concurrent user access.
178	<a href="#">Poptropica</a>	Instance	500,000,000 CA	2007-09-01	As many instanced virtual worlds, the game assigns each user a unique instance to play. Some regions contain common rooms for user meet, chat, and interaction.
179	<a href="#">Fantage</a>	Shard + Instance	30,000,000 CA <sup>74</sup> ; 3,300,000 UV (Monthly) <sup>75</sup>	2008-04-01	The shards of Fantage are deployed in United States, Spain, and Japan <sup>76</sup> . On each shard, users play in the same world. Regions do not have population restriction. Some regions have instanced rooms.
180	<a href="#">MovieStarPlanet</a>	Instance	200,000,000 CA <sup>73</sup>	2009-01-01	Same as Roblox

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