Computerized Dungeons and Randomly Generated Worlds: From *Rogue* to *Minecraft*

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Replayability is a major factor in the long-term enjoyment of a video game. Many games can be engrossing on the first playthrough, but those with fixed solutions and singular paths through multiple levels of skill can quickly lose their appeal after the first win. One approach to replayability is randomly generated content, which ensures a different playthrough each time. While numerous roleplaying games simulate dice rolls, procedural generation in games used predefined seed values in combination with pseudorandom number generators to create entire levels and item sets. *Rogue* is one of the earliest examples of games to focus core gameplay elements around randomly generated levels and items, and its popularity within the UNIX community led to a group of dedicated fans making their own improvements on the game and sharing their modifications online. These derivatives of *Rogue*, known as "roguelikes," have more than a 30-year history of development, and many are still maintained to this day.

The growing popularity of the Internet in the mid-1990s led to many elements of roguelikes branching out from the niche audience of the UNIX community into mainstream gaming. Dungeon crawl games such as *Diablo*, as well as sandbox games such as *Dwarf Fortress* and *Minecraft* have a great deal of randomly generated content, and while none are technically roguelikes, they all draw inspiration from the genre.

The blocky graphics of *Minecraft* are in a sense as crude as the ASCII-based tiles of roguelikes in the 1980s. Many contemporary mainstream games trend toward using high-powered graphics processing units to display realistic graphics. In contrast, *Minecraft*, like *Rogue*, focuses more on interactivity, puzzle solving, and replay. Critically acclaimed and commercially successful, it continues to captivate a younger generation of gamers. In many ways, its randomly generated worlds and massive modification community parallels the development of the roguelike community that thrived throughout the 1980s and 1990s.

> In the late 1970s, dungeon crawl video games pioneered the use of procedural generation to create replayable randomized worlds.

I. CONCEPTUAL PRECURSORS: TOLKIEN AND *DUNGEONS AND DRAGONS*

The 1937 publication of J.R.R. Tolkien's *The Hobbit* [1] and its three-part sequel, *Lord of the Rings*, published between 1954 and 1955 [2], are possibly the single biggest influence on the modern fantasy genre, spanning literature, film, and gaming. Tolkien's richly imagined world of Middle Earth introduced and popularized many tropes within the genre. *Dungeons and Dragons* in particular derived several elements from Tolkien's work, and it is possibly the most influential gaming system [3]. The first edition, released in 1974 by Gary Gygax and Dave Arneson, was wildly successful, played by an estimated 20 million people and generating $1 billion in sales [4]. A pen and paper game, its world is controlled by a player called the dungeon master who narrates the action and story of the game to the other players, who each role plays a character who interacts with the world. Combat, movement, and mechanics are determined by mathematical tables, statistics, and dice to simulate random number generation. The nature of the game is extremely open ended, which allowed for an incredible degree of flexibility. Players could purchase countless commercial expansion packs and rulebooks, as well as write their own [5].

Certain tabletop mechanics of the *Dungeons and Dragons* system quickly manifested themselves in video games. *Adventure* (1976), initially developed by Will Crowther, created a textually described and richly detailed world that allowed the player to interact with the world in a number of ways. *Adventure* spawned the interactive fiction genre, which was typically focused on puzzle solving and story development. Other aspects of the *Dungeons and Dragons* experience, like combat and character advancement (leveling up), took on a different form in dungeon crawl games [6].

II. EARLY DUNGEON CRAWLS ON THE PLATO SYSTEM

The earliest known dungeon crawl computer games appeared on the PLATO System. Launched in 1960 at the University of Illinois and initially running on the ILLIAC I computer [7], PLATO was the first generalized, computer-assisted, instruction system [8]. By 1971, PLATO ran on a CDC mainframe, which was considered a supercomputer at the time [9]. PLATO was accessible from 170 remote terminals by 1975 [10]. Its TUTOR authoring programming language allowed anyone to create new lessons, which ranged widely in academic subject and scope [11].

As PLATO was a shared system, access and resources were limited. The earliest surviving role-playing game on the PLATO system is *pedit5* [12], alternately called *The Dungeon*, written in 1975 by Rusty Rutherford and inspired by *Dungeons and Dragons*. Rutherford worked for the Population and Energy Group at the University of Illinois, Urbana-Champaign, and his group was assigned *pedit1* through *pedit5*. *pedit1* through *pedit3* were programs for the Population and Energy Group, which left two surplus spots for additional usage [13]. The game was frequently deleted as the system administrators determined that gameplay was an inappropriate use of PLATO. An earlier game, *m199h*, appears in some PLATO lesson lists, but the game is lost and little is known about its mechanics. *pedit5* allows the player to generate a character with *Dungeons and Dragons*-inspired statistics: strength, dexterity, hit points, etc., and through a top-down perspective, the player can explore a fixed dungeon and encounter randomly generated monsters [14].

Southern Illinois University students Gary Whisenhunt and Ray Wood played *pedit5* and created their own game by improving and expanding *pedit5*'s concepts. In early 1976, they released *dnd*, which retained *pedit5*'s graphical interface, but expanded the interaction level with the dungeon. The combat and spell system was complex, more items were present, and despite the fact that the game used fixed levels, it was significantly larger [15], [16]. Frequently played by PLATO users, *dnd* and *pedit5* both inspired many other similar games on the PLATO system, including *orthanc* (1978) and the first-person multiplayer-based games *avatar* (1977) and *moria* (1978), which both still have active online communities [17].

III. PROCEDURAL GENERATION AND ROGUE

For its time, PLATO had advanced graphical capabilities that exceeded many of its contemporaries, many of which were still using teleprinters rather than video displays. The 1977 launch of the Apple II, TRS-80, and Commodore PET introduced computing to millions of consumers, and by the early 1980s, newer models of PCs and their games were more sophisticated than the PLATO dungeon crawls in terms of graphics and complexity. One of the earliest PC dungeon crawl games was *Beneath Apple Manor*, initially written for the low-resolution Apple II in 1978 by Don Worth [18], [19]. *Beneath Apple Manor*'s top-down interface is similar to the PLATO system games. However, by using pseudorandom number generators, *Beneath Apple Manor* procedurally generated dungeon levels, which meant that players faced a different dungeon every time they played the game [20].

Beneath Apple Manor's initial graphics were limited by the capabilities of the Apple II low-res display. Personal computers of the late 1970s were unable to emulate PLATO's graphical capabilities, so another approach to game representation was developed through the UNIX system. The *curses* library for UNIX systems was developed by Ken Arnold and released through the Berkeley Software Distribution (BSD) UNIX variant. *curses* enabled the development of text user-interface applications by allowing programs to use cursor addressing, the placing of a character on a specific location on the screen. One of its earliest applications was gaming, and *Rogue* (1980), developed by Michael Toy and Glenn Wichman at the University of California Santa Cruz, was one of the first games to use the *curses* library. Directly inspired by *Dungeons and Dragons* and *Adventure*, *Rogue* has the player explore the procedurally generated Dungeons of Doom to retrieve the Amulet of Yendor. The ASCII tileset was used to represent monsters, items, and dungeon walls, as the use of ASCII was far less processor intensive than drawn graphics. After the initial launch, Ken Arnold later expanded the game and contributed to its development [21].

Both *Rogue* and *Beneath Apple Manor*'s developers were unaware of the others' work [22], but both relied on procedural generation to generate randomized levels, the two earliest video game designers to do so [23]. *Rogue* took randomization one step further to the appearance of items; for example, a tin wand in one game might function totally differently than a tin wand in another game. This level of randomization enhanced the game's replay value and added a layer of difficulty, forcing players to think more strategically about their item usage.

Rogue was popular within the UNIX community as it was packaged with BSD installs starting with version 4.2 in 1983. Extremely popular with universities, BSD 4.2 issued more than 1000 site licenses within 18 months of release [24]. By 1984, *Rogue* had been ported to DOS and Macintosh operating systems, and by the end of the decade the Amiga, Commodore 64, and Atari 8-bit. BSD's widespread distribution allowed any user with access to a terminal to play *Rogue* for free, and it was played on UNIX systems more than its commercial ports, which sold modestly [25].

IV. *HACK* AND *NETHACK*

Rogue's popularity in the UNIX community shortly led to the development of derivatives. After attending the 1982 USENIX conference, Jay Fenlason with assistance from Kenny Woodland, Mike Thome, and Jon Payne, developed a game called *Hack*, which was published on a 1984 USENIX software distribution tape [26]. The game was also popular within the UNIX community, and in 1984 Andries Brouwer vastly expanded the game, publicly releasing *Hack 1.0*'s source code to Usenet in December. *Hack* went through several modifications, and in 1987, Mike Stephenson published an expanded and revised version called *NetHack* to Usenet's newsgroup comp.sources.games [27].

In the late 1980s and early 1990s, a dedicated development team began regular updates of *NetHack*. The team included MIT professor of philosophy Izchak Miller who, after his passing in 1994, was permanently integrated into the game as a shopkeeper [28]. The game was developed throughout the 1990s, and version 3.4.3 was released in 2003. Progress on the game then halted for 12 years until the release of 3.6.0 in December 2015 [29].

Being a direct descendant of *Hack*, which in turn was a descendant of *Rogue*, *NetHack* incorporates much of *Rogue's* interface, language, tileset, descriptions, and systems, but it contains a much richer world. Drawing on Tolkien, science fiction, popular culture, and literary and mythological references, the game's hefty number of in-jokes and references add to the quirky pastiche of the game's world. One of the monsters, the Quantum Mechanic Q, is guaranteed to contain a box in its inventory, the contents of which contain a cat that is either alive or dead. The only function of a credit card in the game is to unlock doors, and one of the dungeon branches is an elaborate game of *Sokoban*, a Japanese puzzle game. Its complexity allows for far greater replay value than *Rogue*, and still has an active community today. The largest public *NetHack* server, nethack.alt.org, has registered 3.5 million games played to date, many of which are recorded for playback [30]. *NetHack* itself has also spawned several variants including *UnNetHack* [31] and *SLASH'EM (Super Lotsa Added Stuff Hack–Extended Magic)* [32]. *NetHack's* release of version 3.6.0 in December 2015 makes it one of the oldest video games still in development [33]. July 2017 marks its 30th anniversary, and while its complexity far exceeds that of *Rogue*, *Hack*, or even the early versions of *NetHack*, it can easily be seen as the spiritual successor to *Rogue*.

V. ROGUELIKES: *MORIA, UMORIA,* AND *ANGBAND*

While *Hack* is a descendant of *Rogue* that deliberately tried to recreate the game, many other games were developed in the 1980s that were similar to *Rogue* but not necessarily direct descendants. These games, created to be more than just enhancements and modifications to *Rogue*, are considered to be a part of the "roguelike" genre. One of the more influential members of the genre was *Moria*, not to be confused with the lower case titled PLATO game of the same name. *Moria* was initially developed for VMS systems by Robert Koeneke in 1983 [34], and is heavily inspired by *Rogue* and Koeneke's Tolkien-themed *Dungeons and Dragons* campaigns, the game itself named after the underground mines encountered in Tolkien's *The Fellowship of the Ring* [35]. In addition to fantasy role playing, one of Koeneke's hobbies was spelunking, and he set out to recreate *Rogue's* basic interface in a massive cave system. While its objectives and interface are similar, the dungeon levels are far more complex. Each dungeon level of *Rogue* and the *Hack* lines were confined to the 80 × 25 lines of text that a computer screen was able to display. *Moria's* dungeon levels were able to span multiple screens, creating a far more elaborate dungeon to explore. The object of the game is to descend through procedurally generated levels, except rather than retrieving an item, the condition for winning the game is killing the Balrog, the monster encountered by Frodo and his party in *The Fellowship of the Ring. Moria* incorporated much of *Rogue's* interface: both the visual elements, such as using letters for the bestiary and the @ character to represent the player, but also in the combat mechanics and randomization of items. In many ways, *Moria* was more sophisticated than *Rogue*, and *Rogue* developer Michael Toy took notice of the game, praising it as being closer to his initial vision than *Rogue* was [36].

Koeneke released several versions of *Moria*, the last being 4.8 in 1987 [37]. The initial versions of the game were written in PASCAL and several people asked for Koeneke's permission to port the game to C and UNIX systems. He was happy to agree as long as he received proper credit for the game's initial development [38]. As with *Hack*, the distribution of the source code allowed *Moria* to spawn several derivative descendants, the first of which was *Umoria* (1988) [39], written in C for UNIX and DOS
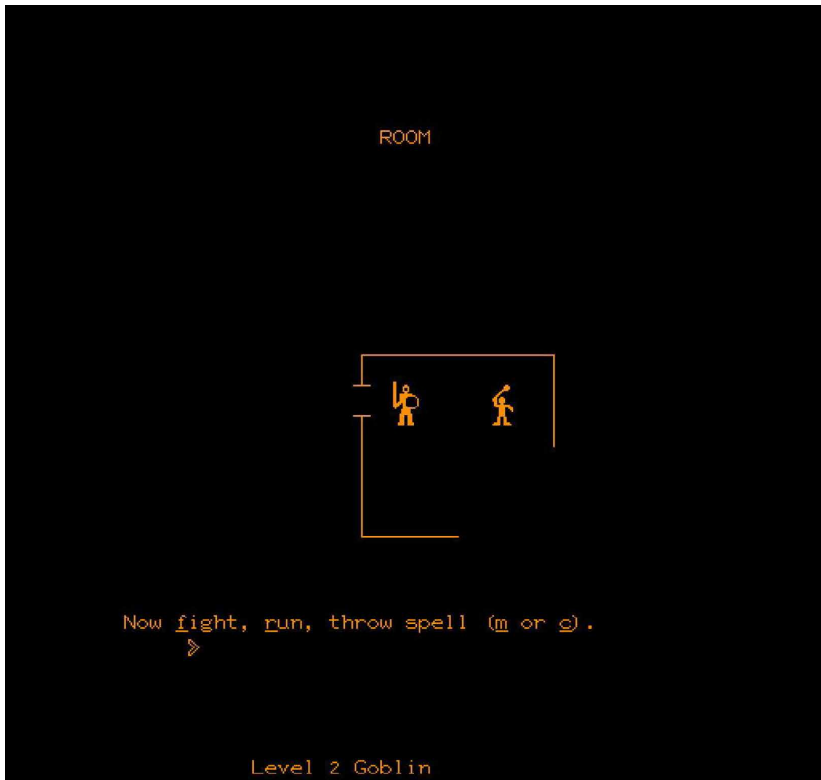
ROOM

Now fight, run, throw spell (m or c).

Level 2 Goblin

Fig. 1. Monster encounter in *pedit5* on cyber1.org server (all screenshots by the author).

systems by Jim Wilson [40]. Since version 5.6, *Umoria* has been free software under the General Public License [41].

Several students at the University of Warwick were fans of *Umoria* and developed their own game called *Angband* (1990). Retaining much of the Tolkien theme, *Angband* greatly expanded *Umoria's* size. The initial version was developed by Alex Cutler and Andy Astrad and, after they graduated, was passed on to Sean Marsh and Geoff Hill. Marsh and Hill released a public version in 1993 for UNIX systems [42]. This code was passed around by several developers via Usenet; in the 1990s it was worked on by Charles Swiger and Ben Harrison, and during the 2000s by Robert Ruehlmann, Jonathan Ellis, Matthias Kurzke, among several others [43]. Functionally very similar to *Moria*, it is still maintained with occasional updates. The latest version, 4.0.5, was released on April 17, 2016 [44].

VI. OMEGA, ANCIENT DOMAINS OF MYSTERY, AND USENET

The gameplay focus of most roguelikes was not on plot advancement, but instead puzzle solving, resource management, and dungeon exploration. The end goal of many roguelikes usually involved descent to the bottom of the dungeon and performing a special task. In the *Hack* lines, it is to retrieve the Amulet of Yendor; in the *Moria* lines, it is to defeat the Balrog or Sauron. A roguelike *Omega* (1988), written by Laurence Brothers during his tenure at the Rutgers University Department of Computer Science, introduced elements comparable to contemporary, plot-based, role-playing, computer game franchises like *Ultima* and *Might and Magic*, such as an overworld, several nonlinear paths to victory, side quests, and active plot development. An unusual quirk of the game is that

it allows one to "play yourself," where rather than using dice rolls, the game will ask you about your academic and sporting career to determine character attributes [45].

German software engineer Thomas Biskup's early forays into gamemaking were focused on making a game that was similar to *NetHack*, but his early attempts were without much success. After several years of planning, Biskup's breakthrough was expanding on *Omega's* use of an overworld and plot advancement, creating a rich environment with forests, mountains, and rivers on top of randomized dungeons. This game became *Ancient Domains of Mystery (ADOM)*, and the first version was released in 1996 [46]. Though the game retained many familiar roguelike visual and procedurally generated elements, it also focused on a nonlinear path with several side quests the player could embark on. Differing from the *Hack* and *Moria* lines, *ADOM* has 13 possible ways to end the game, seven of which can be considered a win [47]. The focus on variety of playing styles and winning conditions offers a great deal of replayability not possible in a game like *NetHack*, where even if the player chooses a different class or set of behavioral conduct, the end goal is always the same. *ADOM* also differs from many other roguelikes in that Biskup maintained control over the source code. After a long hiatus and a successful crowdfunding campaign in 2012, he has been updating the game, the latest update being on October 16, 2016 [48].

Ancient Domains of Mystery received a wide range of publicity and was voted the best downloadable PC game by World Charts in April 1997 [49] [50]. Like many other roguelikes, its fan community was on Usenet. Groups like rec.games.roguelike.nethack and rec.games.roguelike.angband received a fair amount of traffic around this time and rec.games.roguelike.adom was established in 1997 [51]. While *ADOM's*
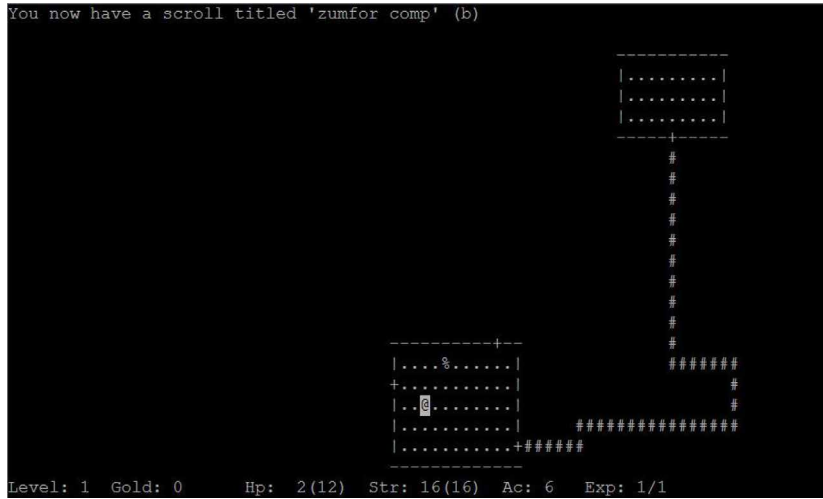
```
You now have a scroll titled 'zumfor comp' (b)
                                                      -----------
                                                     |.........|
                                                     |.........|
                                                     |.........|
                                                     -----+-----
                                                          #
                                                          #
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                   ----------+--                          #
                  |....%.....|                          ######
                  +..........|                               #
                  |..@.......|                               #
                  |..........|                    ###############
                  |..........+######
                   -------------
Level: 1  Gold: 0        Hp:  2(12)   Str: 16(16)  Ac: 6   Exp: 1/1
```

Fig. 2. Rogue 4.0 on a UNIX system, displaying randomized item appearance.

1980s, however, computer graphics had become far more sophisticated. As computer processing power increased, later roguelikes sometimes replaced the ASCII tileset with a graphical tileset, such as *Castle of the Winds* (1989), released for Microsoft Windows systems, or *Torneko no Daibōken: Fushigi no Dungeon* (1993) for the Super Nintendo. More recent versions of *NetHack, Angband*, and *Ancient Domains of Mystery* also came with an option for graphical tilesets to replace the ASCII characters, which offer the player a more modern visual interface.

While popular with certain niches of gamers, roguelikes have received little recognition in mainstream gaming. In addition to the obtuse interface and ASCII graphics, roguelikes tend to be

closed source was an outlier among the major roguelike branches, the *Hack* and *Moria* development teams distributed their source code through Usenet and actively encouraged modifications and variants.

rec.games.roguelike.development, a group dedicated to independent and unique roguelike developments, was created shortly after *ADOM*'s popularity exploded, and the first version of its FAQ was posted on May 31, 1998 [52]. This group's focus was to encompass all aspects of roguelike development beyond tweaking existing games, and it offered a space where developers could work communally on their games by sharing code. Posts were geared toward both the mechanics of designing a procedurally generated world, but also the coordination of conceptual and thematic elements of games, and the forum structure of Usenet allowed users to easily maintain a threaded back-and-forth discussion.

inherited from *Rogue*'s use of the UNIX *curses* library. By the late

VII. COFFEEBREAK AND ROGUELITES

Roguelikes typically used an ASCII tileset to process visual data efficiently when computer processing was incapable of rendering pixel graphics in real time, a tradition

```
34    clear();
35    /*
36     * Free up the monsters on the last level
37     */
38    for (tp = mlist; tp != NULL; tp = next(tp))
39        free_list(tp->t_pack);
40    free_list(mlist);
41    /*
42     * Throw away stuff left on the previous level (if anything)
43     */
44    free_list(lvl_obj);
45    do_rooms();              /* Draw rooms */
46    do_passages();           /* Draw passages */
47    no_food++;
48    put_things();            /* Place objects (if any) */
49    /*
50     * Place the traps
51     */
52    if (rnd(10) < level)
53    {
54    ntraps = rnd(level / 4) + 1;
55    if (ntraps > MAXTRAPS)
56        ntraps = MAXTRAPS;
57    i = ntraps;
58    while (i--)
59    {
60        /*
61         * not only wouldn't it be NICE to have traps in mazes
62         * (not that we care about being nice), since the trap
63         * number is stored where the passage number is, we
64         * can't actually do it.
65         */
66        do
67        {
68        find_floor((struct room *) NULL, &stairs, FALSE, FALSE);
69        } while (chat(stairs.y, stairs.x) != FLOOR);
70        sp = &flat(stairs.y, stairs.x);
71        *sp &= ~F_REAL;
72        *sp |= rnd(NTRAPS);
73    }
74    }
75    /*
76     * Place the staircase down.
77     */
78    i = 0;
79    find_floor((struct room *) NULL, &stairs, FALSE, FALSE);
80    chat(stairs.y, stairs.x) = STAIRS;
```

Fig. 3. Procedural generation of levels in *Rogue* version 5.2.

Fig. 4. *NetHack* on the nethack.alt.org server.

incredibly difficult, where it is possible for players to go for years without a win [53]. *NetHack* in particular is notoriously difficult, and players often swap stories of some of their more amusing failures, known as yet another stupid death (YASD) [54]. Permadeath, a common feature across the major roguelike branches, means that when the player dies, the save file is deleted and they have to start all over from the beginning.

The difficulty of these games can be a drawback to casual players. In the early 2000s, some groups in roguelike development moved toward a broader audience by reducing the learning curve. These games were known as coffeebreak roguelikes, as in a game that

one could easily jump into and play a level or two on a 15-min coffee break. *DoomRL* (2002, now *DRL* after threatened legal action from ZeniMax), a take on the popular 1993 first-person shooter, features a simplified interface, difficulty settings, and digitized sound, and it allows the player to easily start playing without reading comprehensive instructions or having prior experience [55]. These creative approaches to expand the appeal of the genre energized the development community. The first *7 Day Roguelike Challenge* was held in 2005, a development contest where contestants are tasked with developing a roguelike game from start to finish within 168 hours [56]. While

many contestants fail during the process, many of these half-finished games serve as springboards for future development projects [57].

In an attempt to establish more defined parameters for the genre, the International Roguelike Development Conference held in 2008 in Berlin offered a definition that covers factors including randomized procedural generation of rooms and items, permadeath, turn-based movement, focus on combat rather than story or plot, resource management, high level of interactivity, and single-player gameplay [58].

With the mainstream PC game market expanding in the 1990s and 2000s, game developers inspired by roguelikes developed a number of role-playing games geared for broader audiences by removing some of the features that made them difficult for new gamers. DreamForge's *Dungeon Hack* (1993) offered a randomized dungeon, but with first-person graphics and savepoints; and Blizzard's *Diablo* franchise, inspired by *Angband*, which integrated randomly generated levels with real-time play; and *Diablo II* (2000) which featured a "hardcore" game mode which enabled permadeath. Games that feature certain elements of roguelikes, but present them in a more user-friendly fashion, are colloquially known as "roguelites." Some recent and critically acclaimed roguelites include *The Binding of Isaac* (2011) and *FTL: Faster than Light* (2012).

VIII. INFLUENCE OF PROCEDURAL GENERATION BEYOND ROGUELIKES

Some features of roguelikes have influenced mainstream computer role-playing games, procedural generation in particular has seen increased interest as a means to create large-scale environments with a great deal of replayability. Some games are using randomized content to not only generate individual dungeon levels, but entire worlds. *Dwarf Fortress*, designed by Tarn and Zach Adams, has been in development since 2002 [59], and randomly generates cave
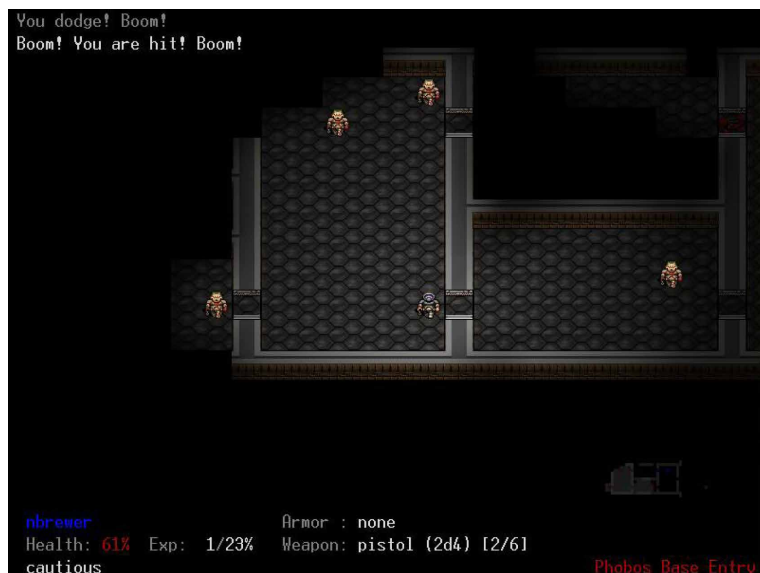

Fig. 5. Exploring an outlaw settlement in *Ancient Domains of Mystery*.

Fig. 6. *DRL* using graphical tileset.

systems and mines, as well as the history, culture, and lore of the world itself [60]. Retaining the visual elements of ASCII to save on graphics processing, *Dwarf Fortress* uses the computer's processing power to generate massive amounts of terrain. It is comparable to a sandbox simulator like *Sim City* in that it does not have any concrete endpoints where the player "wins," but instead offers an experience where the player can monitor and aid in the growth of a civilization.

Popular within the indie gaming community, *Dwarf Fortress* was one of the main inspirations behind *Minecraft* (2009) [61]. Stripping away some of the more difficult elements of *Dwarf Fortress*, whose unofficial motto is "losing is fun"

[62], *Minecraft* procedurally generates a world that is roughly seven times the surface area of Earth [63]. Also set in a sandbox environment, the game is typically run on online servers, so players can collaborate with others on various building projects. In addition to exploring the surface of the world, *Minecraft* generates massive subterranean cave systems filled with hostile monsters and treasure. Its developers encourage modification communities, and there are several expansion packs to make the game's cave systems function like a traditional dungeon crawl. *Minecraft* is still incredibly popular, and to date has sold over 100 million copies [64], making it the second best-selling video game of all time, behind *Tetris* [65].

Following the success of *Minecraft*, trends toward procedurally generating massive worlds have become more prominent within mainstream gaming. *No Man's Sky* (2016) generates a universe containing 16 quintillion unique planets [66], and while it received mixed critical reviews, it was commercially successful and received coverage in many mainstream gaming publications [67]. Likewise, the upcoming *Star Citizen* received over $50 million in crowdfunding [68], currently the largest crowdfunding project of all time [69]. It promises a procedurally generated universe that comprises at least 400 quadrillion cubic kilometers in an online MMORPG setting [70].

While these large procedurally generated worlds have received recent success in the mainstream gaming community, *NetHack, Angband,* and *Ancient Domains of Mystery* are still being developed and have active, if niche, fanbases. To date almost 1000 roguelike games have been cataloged on the RogueBasin site, a wiki dedicated to the genre [71], and several guides and toolkits exist for roguelike development [72]. *Rogue*'s influence goes far beyond its own genre and has been instrumental in shaping the development of computerized role-playing games as a whole. Though many modern games incorporate sophisticated graphics and voice acting to bridge the gap between interactive fiction storytelling and dungeon crawl elements, the roguelike remains a popular avenue for independent game developers to create vastly expansive and replayable worlds. ∎

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