Luck and Roguelikes

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This began as a `README` file for pseudo random distribution practice code[1] but at some point evolved into a longer discussion on randomness and luck and related functions.

Some knowledge (but not much) of statistics and role playing games is assumed. For the games aspect if you know what 3d6 means you will probably be fine; for the statistics, a few Khan Academy videos or a chapter or two of an introductory book on statistics should more than suffice. You may also want to know a bit about C. And unix.

Pseudo Random Distributions

Pseudo Random Distribution (PRD) are used in games to make the Random Number Generator (RNG) less likely to go on long runs of hits or misses. A RNG with more fibre in its diet, in other words. Briefly, when an ability activates the chance of activation is reset to a very low value; this value increases with each miss and will either reach 100% or wrap around to the lowest activation value depending on how the PRD is designed (or it could segfault, but those versions tend to be fixed before public release). The table of odds is usually designed such that on average the chance of activation works out to some published value–say, 25%–though a PRD will have different statistical properties than a straight check against the RNG. More on this, later.

Use of a PRD reduces the influence of luck; without a PRD a mage may fail their 75% chance-to-activate spell three times in a row, die, and then complain that the spell "ought to" activate somewhere around three times out of four attempts, or otherwise certainly not fail three times in a row, I mean did Gandalf ever flub a spell? No! (etc.) This is the Gambler's Fallacy; a PRD attempts to make the fallacy true. With a PRD the inverse will also be true; the mage will be less likely to see multiple activations of their spell in a row as the chance to activate decreases following each activation.

A downside of PRD is that state must be maintained. There may thus be scaling issues as the number of abilities and entities tracked increase; normal attacks might instead use the RNG directly to avoid this problem–possibly with multiple dice; 3d6 averages out better than a similar roll of a 1d20–and a PRD might only be used for select abilities, possibly those that have tactical uses, or where too frequent an activation would be as problematic as too rare, and the cost of maintaining state is a necessary evil.

[1] `https://github.com/thrig/ministry-of-silly-vaults/tree/master/pseudo-random-dist`

Enough with the Prose; Code

```
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>

#define TRIALS 10000

#define PRD_COLS 7
uint32_t odds[PRD_COLS] = { 128849018, 730144440, 1245540515,
    1589137899, 1846835937, 2534030704, 3564822855 };

int main(void) {
    int counter = 0, hits = 0;
    for (int t = 0; t < TRIALS; t++) {
        if (arc4random() <= odds[counter]) {
            hits++;
            counter = 0;
        } else {
            counter = counter >= PRD_COLS ? 0 : counter + 1;
        }
    }
    printf("%g\n", hits / (double) TRIALS);
    return 0;
}
```

This uses the `arc4random(3)`[2] call and checks whether the random value is below a magic number looked up from the `odds` array. Any other RNG function could be used, though be sure to read the documentation for that function carefully: functions such as `random(3)`[3] only return 31 bits of random data, or the function may require seeding. The magic numbers are odds based on the maximum value possible from the `arc4random(3)` call, 4294967295. This implementation will wrap around should the 83% chance 3564822855 fail. With 4294967295 placed at the end of the list the attempt would always succeed after however many attempts are in the list.

```
% make prng
cc -std=c99 -O3 -Wall -pedantic -pipe   -o prng prng.c
% ./prng
0.2475
```

These odds produce, on average, slightly below a 25% chance of activation. The `counter` variable in a game would likely instead be associated with some struct or class that represents an entity or skill of some entity; here many trials are run so that the behavior of the PRD can be modeled and compared to a straight 25% check. Or, rather, a 24.57% check, on average:

[2] http://man.openbsd.org/man3/arc4random.3
[3] http://man.openbsd.org/man3/random.3

```
% (repeat 10000 ./prng) | r-fu summary
elements 10000 mean 0.246 range 0.017 min 0.237 max 0.254 sd 0.002

    0%    25%    50%    75%   100%
0.2372 0.2442 0.2457 0.2473 0.2539

% perl -e 'printf "%.f\n", 0.2457 * 2**32'
1055273465
```

r-fu[4] provides integration of R with the unix command line environment; the statistics could be done with any tool. The summary function calculates attributes such as the standard deviation and a quantile of where the values fall. The PRD and a straight check should produce different distributions of values:

```
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>

#define TRIALS 10000

#define PRD_COLS 7
uint32_t odds[PRD_COLS] = { 128849018, 730144440, 1245540515,
    1589137899, 1846835937, 2534030704, 3564822855 };

int main(void) {
    for (int r = 0; r < 10000; r++) {
        int counter = 0, prd_hits = 0, reg_hits = 0;
        for (int t = 0; t < TRIALS; t++) {
            uint32_t v = arc4random();
            if (arc4random() <= odds[counter]) {
                prd_hits++;
                counter = 0;
            } else {
                counter = counter >= PRD_COLS ? 0 : counter + 1;
            }
            if (v <= 1055273465) reg_hits++;
        }
        printf("%g %g\n", prd_hits / (double) TRIALS,
               reg_hits / (double) TRIALS);
    }
    exit(0);
}
```

A comparison of the PRD versus regular output:

```
% make prng-compare
cc -std=c99 -O3 -Wall -pedantic -pipe   -o prng-compare prng-compare.c
```

[4] https://github.com/thrig/r-fu

```
% ./prng-compare | r-fu colsumm - PRD straight
                 PRD     straight
Count    1.000000e+04 1.000000e+04
Range    1.610000e-02 3.620000e-02
Mean     2.457498e-01 2.456503e-01
Sdev     2.241290e-03 4.299170e-03
Min.     2.376000e-01 2.254000e-01
1st Qu. 2.442000e-01 2.428000e-01
Median  2.457000e-01 2.457000e-01
3rd Qu. 2.473000e-01 2.485000e-01
Max.     2.537000e-01 2.616000e-01
```

The range on the straight 25% check is over twice as large, and the standard deviation is almost twice as large while the mean and median are more or less the same. This indicates that the distribution for the PRD is much less spread out, or less random. If possible do your own analysis; there is no telling whether my numbers are wrong or simply made up.

What happens if a 100% success is added to the list of PRD odds? What adjustments would be necessary to bring that new PRD to a ~25% chance of activation?

A More Functional Approach

An implementation in a single language may be prone to bugs; while unit tests and such may help catch those bugs a different implementation in a different language may be a good exercise. Here is a Common LISP implementation of the earlier C code.

```
(setq *random-state* (make-random-state t))

(defun make-prng (odds)
  (let* ((oddslst (copy-list odds))
         (curv 0)
         (maxv (1- (list-length oddslst))))
    #'(lambda ()
        (if (<= (random 1.0) (nth curv oddslst))
            (prog1 t
              (setq curv 0))
            (prog1 nil
              (setq curv (if (>= curv maxv) 0 (1+ curv))))))))

(defmacro when-trigger (call &body body) `(when (funcall ,call) ,@body))

(let ((ability (make-prng '(0.03 0.17 0.29 0.37 0.43 0.59 0.83)))
      (hits 0)
      (trials 10000))
  (dotimes (n trials) (when-trigger ability (incf hits)))
  (format t "~g~%" (/ hits trials)))
```

This version uses a closure on the odds (fractional instead of `uint32_t` values); calls to the function returned work through the odds list in much the same way as in the C code.

```
% sbcl --script prng.lisp
0.2475
```

Concerns with PRD

Given that activations increase in odds according to some table, min/maxers will try to game those activations. Possible solutions might be to reset or randomize the counters at suitable times (such as between combat) but that is more work, and the gaming of the counters may not be an actual problem, or could even be expected for skillful play. For instance a player may try to prime an activation against low-level mooks so that early in a boss fight an activation of an ability happens; if they can plan around activations this may give a min/maxer an advantage over those less considerate of when a PRD is likely to activate.

Throw More Dice at the Problem

As mentioned earlier a 3d6 averages out better than a 1d20; there are more combinations from the three dice that add up to values in the middle of the 3-18 range while a 1d20 should have the same odds for each value between 1 and 20 inclusive. A physical die or RNG may not however attain that ideal[5] for various reasons. So, to average things out we might try using more dice. This does not require state like a PRD does but will draw on the RNG more. Games probably do not draw too much from the RNG; that risk is more for simulations[6] that test billions of events on multiple systems where you do not want the systems using the same numbers from the RNG.

As an example consider the player HP gain code in rogue 3.6.3.[7]

```
/* fight.c */
void check_level(void) {
    int i, add;
    for (i = 0; e_levels[i] != 0; i++)
        if (e_levels[i] > pstats.s_exp) break;
    i++;
    if (i > pstats.s_lvl) {
        add = roll(i-pstats.s_lvl,10);
        max_hp += add;
        if ((pstats.s_hpt += add) > max_hp)
            pstats.s_hpt = max_hp;
        msg("Welcome to level %d", i);
    }
    pstats.s_lvl = i;
}
```

The `roll` call is as follows, and the (bad) `rnd` it uses will be along shortly.

[5] http://www.donationcoder.com/Software/Mouser/dicer/DicerC1.pdf
[6] http://www0.cs.ucl.ac.uk/staff/D.Jones/GoodPracticeRNG.pdf
[7] https://github.com/thrig/rogue36

```
/* main.c */
int roll(int number, int sides) {
    int dtotal = 0;
    while(number--) dtotal += rnd(sides)+1;
    return dtotal;
}
```

Complications aside, this works out to 1d10 HP per level gained and also a heal of that amount should the player not be at maximum HP. This is great if the RNG rolls above average and terrible below–a Hobgoblin hits for 1d8 damage, and a player starts with 12 HP; worst case the player will have 13 and 14 HP at experience levels two and three. This impacts the rest of the game: more time might be spent healing (monster spawns. . .) with the chance that the dungeon may not offer useful equipment and then the first serious threat will likely kill the player, or they will have to dive to the stairs, miss resources, and find even stronger monsters. No matter how skillfully a player plays bad luck on the HP gain could ruin the run.

Roguelikes are lethal; one opinion is that the game should sometimes rip the player's head off. If luck should play less of a role the HP gain might instead be a fixed amount (a Brogue[8] potion of life indicates what percentage your life increases by) or otherwise less random. Less random can be done by throwing more dice at the problem, perhaps we roll 5d2 for HP instead of 1d10. Monte Carlo simulations with the RNG used in the game will help model the player HP over a set number of levels. A 1d10 version:

```
#include <stdio.h>
#include <stdlib.h>

int seed;
#define RN (((seed = seed*11109+13849) & 0x7fff) >> 1)
int rnd(int range) {
    return range == 0 ? 0 : abs(RN) % range;
}

int main(void) {
    for (int t = 0; t < 10000; t++) {
        seed = (int) arc4random();
        int hp = 12;
        for (int level = 0; level < 8; level++)
            hp += rnd(10) + 1;
        printf("%d\n", hp);
    }
    return 0;
}
```

Rogue 3.6.3 uses a bad RNG (the state of the art was different in 1980) here seeded to various values by `arc4random(3)` to give an idea of the HP for a player at level 8.

[8] https://sites.google.com/site/broguegame

```
% make hpgain-rogue
cc -std=c99 -O3 -Wall -pedantic -pipe   -o hpgain-rogue hpgain-rogue.c
% ./hpgain-rogue | r-fu summary
elements 10000 mean 55.899 range 56.000 min 28.000 max 84.000 sd 7.958

  0%  25%  50%  75% 100%
  28   50   56   62   84
```

Somewhere between 28 and 84, most likely around 56. If instead 5d2 is used:

```
#include <stdio.h>
#include <stdlib.h>

int seed;
#define RN (((seed = seed*11109+13849) & 0x7fff) >> 1)
int rnd(int range) {
    return range == 0 ? 0 : abs(RN) % range;
}

int main(void) {
    for (int t = 0; t < 10000; t++) {
        seed = (int) arc4random();
        int hp = 12;
        for (int level = 0; level < 8; level++) {
            for (int flip = 0; flip < 5; flip++)
                hp += RN & 1 ? 2 : 1;
        }
        printf("%d\n", hp);
    }
    return 0;
}
```

We find... err... umm...

```
% make hpgain-flip && ./hpgain-flip | r-fu summary
cc -std=c99 -O3 -Wall -pedantic -pipe   -o hpgain-flip hpgain-flip.c
elements 10000 mean 72.000 range 0.000 min 72.000 max 72.000 sd 0.000

  0%  25%  50%  75% 100%
  72   72   72   72   72
```

I did mention that the RNG used by Rogue 3.6.3 is bad, and here we have an example as to why. If the `RN & 1` is replaced with `arc4random() & 1` the values vary as expected:

```
% grep arc4random hpgain-*.c | grep -v seed
hpgain-flip.c:                hp += arc4random() & 1 ? 2 : 1;
hpgain-rogue.c:            hp += arc4random_uniform(10) + 1;
```

```
% make hpgain-flip hpgain-rogue
cc -std=c99 -O3 -Wall -pedantic -pipe   -o hpgain-flip hpgain-flip.c
cc -std=c99 -O3 -Wall -pedantic -pipe   -o hpgain-rogue hpgain-rogue.c
% for p in ./hpgain-rogue ./hpgain-flip; $p | r-fu summary
elements 10000 mean 55.928 range 60.000 min 26.000 max 86.000 sd 8.225

  0%  25%  50%  75% 100%
  26   50   56   62   86

elements 10000 mean 72.051 range 24.000 min 60.000 max 84.000 sd 3.154

  0%  25%  50%  75% 100%
  60   70   72   74   84
```

which shows that 1d10 is more random than 5d2; note in particular the standard deviation and difference in the minimum value. The coinflip standard deviation might even be too low; it could be more efficient to simply give the player a fixed gain per level of hit points, or to raise the minimum value by rolling 1d8+2 instead of 1d10. A higher average HP would need to be play tested or simulated to see if this makes the game too easy; Dungeon Crawl Stone Soup[9] for example offers a fight simulator in wizard mode. With lower variance it is likely easier to plan for close combats as the player should have more predictable HP values over the course of the game, though simulation would also need to take into account other elements of the game such as the gain and use of resources.

Rubber Band Odds

The term "rubber banded" is used by the author of Brogue[10] to describe a method for a less-than-random allocation of critical resources; this design is similar to that of a PRD in that the odds vary depending on circumstance: increased odds deeper in the dungeon, but the odds decrease when an item does generate. Without looking at the source code for Brogue, what can we come up with from this description?

```
(progn (setq *random-state* (make-random-state t)) (values))

(let ((odds 0.7))
  (defun resource? ()
    (setq odds (+ odds 0.15))
    (if (< (random 1.0) odds)
        (prog1 t (setq odds (- odds 0.4)))
        nil)))

(dotimes (level 20) (format t "~d ~a~%" level (resource?)))
```

This prototype generates okay-looking results; it is presumably called when generating a level, with the default odds starting at 0.7 + .15 or 85% that the resource generates on

[9] https://crawl.develz.org/

[10] https://www.rockpapershotgun.com/2015/07/28/how-do-roguelikes-generate-levels/

the first level of the dungeon, or 100% on the second level if it does not generate on the first. There is a -40% hit when the resource does generate. Important questions are how many of the resource generate over the course of a game, and how many does the player need? is there a chance the player will not find the resource, and how bad would that be? what are the odds of a streak of levels not having the resource, and how bad would that be?

The "how many" question is easy to answer: generate a large number of levels, tally up how many of the resource generate and then do statistics on those results. The "streak of levels" is a more difficult question though may be calculated as "how many misses have been seen whenever a resource is found" as complicated by the player's use of resources; streaks of misses may matter less if there are (usually) enough of a resource to tide the player through a bad spot. Let us consider two different cases for the "how many" versus "runs of misses" using hypothetical food resources for an ever-hungry halfling.

Staircakes

Staircakes are a rare treat; the player may choose to consume the ever so delectable staircake (with a large increase in satiation) at the cost of removing a stair from the level map; presumably other code will need to handle the "there is still a route, but it is a longer and more difficult" tradeoff. We therefore want staircakes to only generate a few times per game, and probably not early in the game–there should never be a staircake on the first level. This is easy to solve; set the initial odds to zero or possibly an even lower value. Then, for the expected number of levels in the game tally up how many staircakes generate and tune the change in odds so there is a large decrease when a staircake is found (possibly more than -100%), and a suitable (likely small) increase over time to generate additional staircakes.

Waffles

Waffles are common fare; enough must generate so that our halfling hero (mostly) does not starve to death, assuming they do not spend too much time on the road that "goes ever on and on". Staircakes are a complicating factor though one can probably fudge the numbers based on how often those generate and the expected chance a player will consume them.[11] On the assumption that a waffle need be consumed every three levels the "runs of misses" need not be tracked: food will go negative when there is not enough.

```
(let ((starved 0) (trials 10000))
  (dotimes (n trials)
    (let ((waffles 2))
      (dotimes (level 20)
        (when (zerop (mod level 3)) (decf waffles))
        (when (minusp waffles) (incf starved) (return))
        (when (resource?) (incf waffles)))))
  (format t "~d ~f%~%" starved (* (/ starved trials) 100)))
```

[11]One might anticipate the factions "consume staircakes, always" and "nope, never!" to emerge plus raging discussions as to which choice is best. A smart developer could sell rewards to both sides. Smart players will probably take a moderate approach.

This code with the previous `resource?` function shows the player starving to death in around 1% of games played, or less if one adds staircakes to the equation. If the starting waffle count is decreased from two to just one, the player starves at least once in 25% of games; this would increase the importance of eating staircakes or otherwise not wasting time exploring levels. If the odds are too low the feature could instead be removed: why have food if there's a minimal risk of it having an impact on gameplay? Too high a risk on the other hand the game may not be fun as too many players starve to death.

Improvements to the waffle check code would be to tally how many times (0, 1, . . .) the player starves during a game and to better integrate the influence of staircakes on the hunger level. Another met

```
                   __________
                  /          \
                 /    REST    \
                /      IN      \
               /     PEACE      \
              /                  \
              |       Luck       |
              |      42 Au       |
              |   killed by a    |
              |      snake       |
              |       2018       |
             *|     *  *  *      | *
     ________)/\\_//(\/(/\)/\//\/|_)_______
```

The management would like to apologize
for the sudden and seemingly random
end of this document.

Appendix E

Floating eyes in Rogue pose particular problems when luck is involved, or rather when the player is unlucky. Eyes spawn from D2 through D11 and overlap with Rust monsters on D9 through D11. Eyes are not hostile, unless attacked by the player (and monsters sometimes spawn in places where they must be attacked) or should the player be blessed with a ring of aggravate monsters. Rust monsters were mentioned as they are another zero-damage monster that applies only status effects; a player may be boxed in between two Eyes in a corridor or an Eye and a Rust monster.

```
|........|                            -+-
|........|                       #####+..|
|........+###########E@R########     |..|
-------+--                            ----
```

How can this be a problem?

```
/* fight.c */
    when 'E':
        /*
         * The gaze of the floating eye hypnotizes you
         */
        if (on(player, ISBLIND))
            break;
        if (!no_command)
        {
            addmsg("You are transfixed");
            if (!terse)
                addmsg(" by the gaze of the floating eye.");
            endmsg();
        }
        no_command += rnd(2)+2;

/* command.c */
        if (no_command)
        {
            if (--no_command == 0)
                msg("You can move again.");
        }
        else
```

There is a non-zero risk of a softlock should the Eye hit the player enough times as each hit adds two to three to `no_command` which is only decremented by one each turn. Worse, the player has no move after becoming unparalyzed; this gives the Eye another chance for a hit. Worse, there is no way for the player to starve to death; `stomach` in `daemons.c` only causes the player to sometimes faint, and not if already paralyzed. Hence, there is a risk of a softlock where the game never exits because the player is paralyzed and can neither move nor die.

The critical code is under roll_em from fight.c that determines whether the Eye hits, and whether the player misses though to simplify our model we shall assume the player always misses–a player will win most fights against an Eye. roll_em is complicated; it handles both monsters and the player and various weapon types the player may wield. Some will advise stepping through it with a debugger; I belong more to the "add some print statements" school of thought. A logfile with roll_em results from real games might help with future statistical analysis. . . [12]

```
#include <stdio.h>
#include <stdlib.h>
FILE *dbgfh;
...
    dbgfh = fopen("roll_em", "a");
    if (dbgfh == NULL) abort();
...
    fprintf(dbgfh, "alvl=%d def_ac=%d wplus=%d\n", att->s_lvl, def_arm,
            hplus + str_plus(&att->s_str));
```

Anyways, the relevant code from roll_em is the player's defence and whether the "swing" of the Eye connects,

```
    if (swing(att->s_lvl, def_arm, hplus+str_plus(&att->s_str)))
```

where the s_lvl of an Eye is 1 and the player def_arm will depend on their armor and whether they are wearing any rings of protection. Rust monsters have a strong influence on armor; a player on D9 through D11 will likely have a worse AC than on earlier levels. swing is a d20 roll as found in Dungeons & Dragons.

```
int
swing(int at_lvl, int op_arm, int wplus)
{
    int res = rnd(20)+1;
    int need = (21-at_lvl)-op_arm;

    return (res+wplus >= need);
}
```

wplus is difficult to track down as the details are scattered through init.c and monsters.c though for an Eye is 0. With some algebra swing may be converted into a test whether the player (of a given armor class) is frozen:

```
int gaze(int player_ac)
{
    int res = rnd(20) + 1;
    int need = 20 - player_ac;

    return (res >= need);
}
```

[12] Another option is some sort of logging API or database, which is viable if you happen to have one of those just lying around, or when you operate at a scale that demands such, or when you've written a bunch of similar games and have abstracted out logging for the damage function.

The player armor is the deciding factor if we (again) ignore the likely case where the player first kills the Eye before it can get a paralyze in. If not. . .

```
int softlock(int player_ac, int limit)
{
    int no_command = 0;
    int i;
    for (i = 0; i < limit; i++) {
        if (gaze(player_ac)) no_command += rnd(2) + 2;
        /* TWEAK - what happens if one or more rnd calls are made here? */
        //rnd(100);
        if (no_command) --no_command;
        if (no_command == 0) break;
    }
    return (i == limit) ? 1 : 0;
}
```

Similar to how fractals are calculated the above tests whether the player has no moves up to some limit. Over many different seeds and many trials and using a limit of 10,000 the mean odds of the player having no move for various armor values is as follows.

AC	Odds
6	0%
8	12%
10	32%
12	47%

These numbers are approximate, as the use of `rnd` is likely not the same as in the game. That is, other calls to `rnd` will influence these results because the generator (as shown above) is bad. Uncomment the `rnd(100)` in `softlock` and compare the output of new runs to see this difference. AC 6 may see lock runs of 100 or more turns if the player is very unlucky, but never 10,000.

With two `E` attacking the player in a corridor the situation would be even worse; woe to the player with a ring of aggravate monsters and bad armor–and an AC of 9 or 10 is common on D9 and onwards due to Rust monsters.

Possible Solutions to Avoid or Limit the Risk of Softlock

- Add code to prevent paralyzation for some number of turns following a paralyze.[13]
- Adjust the food code so the player can actually starve to death.
- Alter Floating eye generation to not overlap with Rust monsters.
- Cause Floating eyes to summon monsters.[14] Probably bad with Rogue corridors.

[13] Crawl added this to prevent repeated banishment to the Abyss by the banishment spell.
[14] POWDER does this.

- Eliminate Floating eyes from the game.
- Make Floating eyes do a very small amount of damage so the player can die to one.
- Make players of higher levels less likely to be affected.
- Only increment `no_command` when the player is not already paralyzed, possibly in conjunction with a longer base duration.
- Set a cap on the maximum duration a player can be paralyzed.

Some of these may require significant code changes or may significantly change the game. For example `command.c` gives the monsters a move after the player can move again; this may lead to a different form of a softlock where the player would be pressing space to clear an endless stream of messages related to their paralyze status.

Appendix D

Doors, in particular the search for hidden doors, are the concern of this section. Dungeon Crawl Stone Soup has long since removed secret doors, and Brogue as of version 1.7.5 has changed search to lower the chance that the player must wander around searching for some hidden room that contains the stairs down to the next level. What problem are these changes trying to solve? The rogue 3.6.3 door search code is simply:[15]

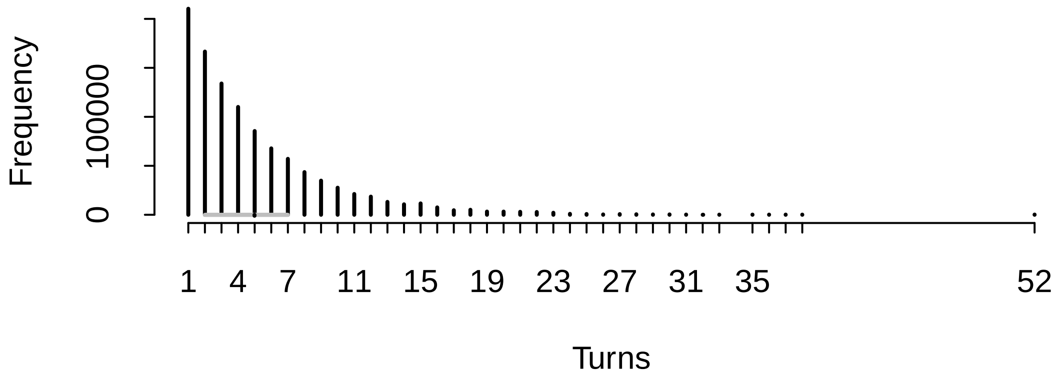
```
case SECRETDOOR:
    if (rnd(100) < 20) {
        mvaddch(y, x, DOOR);
        ...
```

So, a 20% chance to find a hidden door on each search attempt. (Brogue extends the range of the search; rogue only searches directly adjacent squares.) A monte carlo simulation will illustrate the problem with the above code;

```
int search(void)
{
    int turns = 1;
    while (1) {
        if (rnd(100) < 20) break;
        turns++;
    }
    return turns;
}
```

or in other words calculate how many turns it takes a door to be found. This `search` function will need be run with many different seeds for many different trials to get an idea of how (the again very bad) `rnd` function behaves.

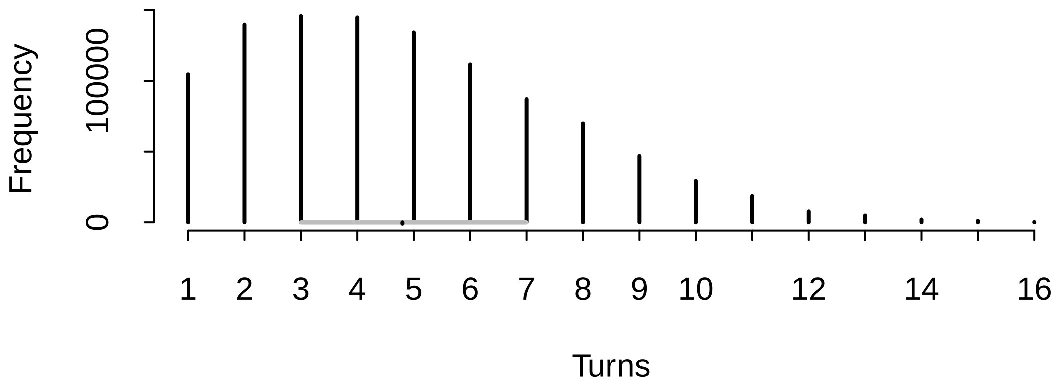
[15]There are rings of searching; wearing those causes the same search code to run once or twice each turn.



The good news is that most of the time the player will find a door in under 10 turns (about a 90% chance). The bad news is if the RNG is in a bad mood it may take significantly longer to find the door. If instead the odds increase on repeated searches (that is, if the player searches without moving–moving resets the repeated search counter) via something like the following:

```
int new_search(void)
{
    int turns = 0;
    while (1) {
        if (rnd(100) < 10 + 4 * turns++)
            break;
    }
    return turns;
}
```

The initial odds are lower, though a simulation of this new function shows that the long tail has been reduced to at most ~16 turns:



Appendix Z

ZAngband 2.6.2 presents portability problems, in particular 100% CPU use during character generation. This turns out to be a RNG problem. Investigation of the source reveals that the RNG is seeded[16] poorly, much like the choice of a cup in an Indiana Jones movie.

```
% grep 'seed =' src/dungeon.c
                seed = (time(NULL));
                seed = ((seed >> 3) * (getpid() * 2));
```

However this is not cause of the CPU bug, rather a weakness that may be exploited by a crafty player to guess or know what the RNG will roll, one that may be fixed via `arc4random(3)` or by reading 32 bits from `/dev/urandom`.

The CPU usage can be debugged up a macro, or rather a series of macros in `src/z-rand.h` that have the bonus of not allowing my debugger step through the critical `Rand_div` function.

```
#define randint1(M) \
        (randint0(M) + 1)
#define randint0(M) \
        ((s32b)Rand_div(M))
```

`Rand_div` is complicated; it contains not one but two different RNG. Replacing this entire function with an equivalent `arc4random_uniform` call leads to map generation failures due to `arc4random_uniform` being too random compared to what the original function produces, in particular to the outputs of the "simple RNG". So no simple fix here; the code depends on particular values from the particular RNG used. The CPU bug, however, is in the "complex RNG" portion of the code; somewhere in `src/birth.c` character attributes are rolled up in the Dungeons & Dragons tradition:

```
        while (TRUE)
        {
                /* Roll some dice */
                for (j = i = 0; i < 18; i++)
                {
                        /* Roll the dice */
                        dice[i] = randint1(3 + i % 3);
```

with lots of dice rolls to obtain better stats; in a real-life game a nice Dungeon Master would let a player re-roll a bad attribute roll; here that instead is brute forced. (If you're going to allow the player to obtain good stats, there are more CPU efficient ways to do that. Anyways!) With lots of rolls, much time is spent in `Rand_div` by way of the `randint1` macro, which for debugging can be temporarily replaced by a direct function call:

```
                        dice[i] = 1 + Rand_div(3 + i % 3);
```

This in a debugger shows much spinning around in the loop:

[16] https://flak.tedunangst.com/post/random-in-the-wild

```
while (1) {
        int j;
        j = Rand_place + 1;
        if (j == RAND_DEG) j = 0;
        r = (Rand_state[j] += Rand_state[Rand_place]);
        r = (r >> 4) / n;
        Rand_place = j;
        if (r < m) break;
}
```

Most values for `r` are larger than `m` so the loop almost never exits, unless one is extremely patient or has an extremely fast CPU. `m` is the input to `Rand_div`, here values in the range of three to five, inclusive. `r` meanwhile is `u32b` which appears to be a unsigned 32-bit value, or what `stdint.h` (now, but not when ZAngband was being developed) provides as `uint32_t`. Over in `src/h-type.h` we find:

```
/* Signed/Unsigned 32 bit value */
#ifdef L64      /* 64 bit longs */
typedef signed int s32b;
typedef unsigned int u32b;
#else
typedef signed long s32b;
typedef unsigned long u32b;
#endif
```

Where `L64` is only set on DEC Alpha OSF systems. So on my 64-bit system (OpenBSD 6.5, amd64) the `s32b` and `u32b` are actually eight instead of four byte containers.

```
% cfu 'printf("%lu\n", sizeof(unsigned long))'
8
% cfu 'printf("%lu\n", sizeof(uint32_t))'
4
```

This well explains why the RNG has problems; the `Rand_state` is permuting 64-bit values instead of the expected 32-bit values... someone could work out exactly why this is bad for the algorithm involved, but the fix here is to make `s32b` and `u32b` use proper 32-bit containers on all 64-bit systems.