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

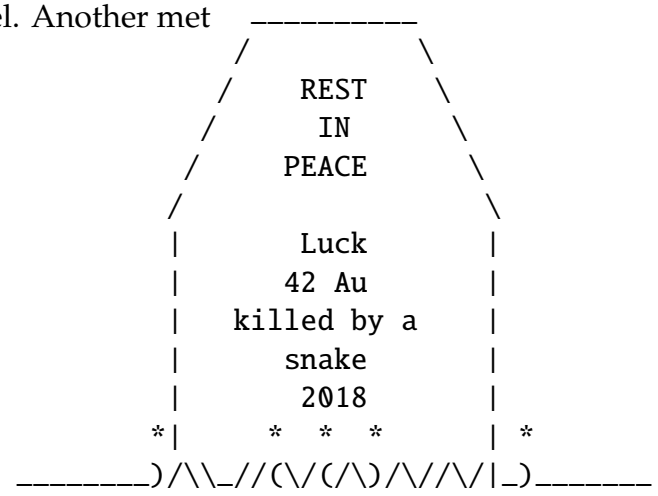
Waffles are common fare; enough must generate so that our halfling hero (mostly) does not starve to death, assuming they do not spend too much time on the road that "goes ever on and on". Staircakes are a complicating factor though one can probably fudge the numbers based on how often those generate 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



The management would like to apologize
for the sudden and seemingly random
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