

When Random is Too Random

Hendrik Demmer



About me

- Studied maths
- 7 years in Berlin game companies
(3 years at Wooga)
- Now a Freelance Engineer
- Opinions expressed are my own
- I <3 Randomness!



Random Berlin picture



Suspense

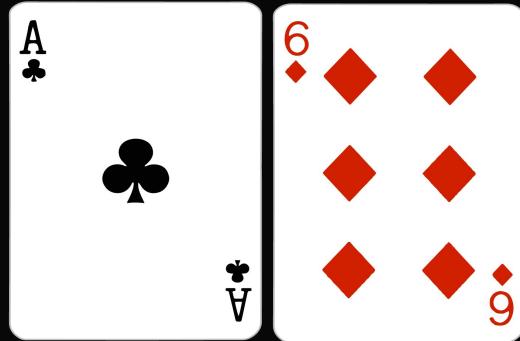
- You know something is going to happen.
 - But until it happens you don't know what it is.

Our brains love this!

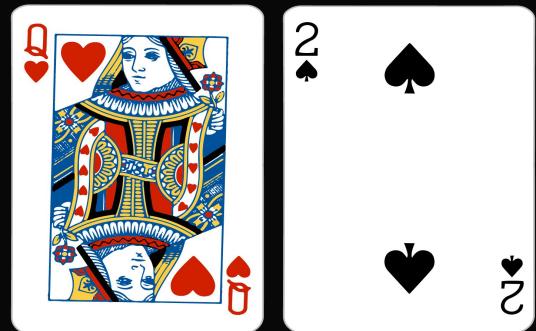


Hitchcock

Suspense through Randomness

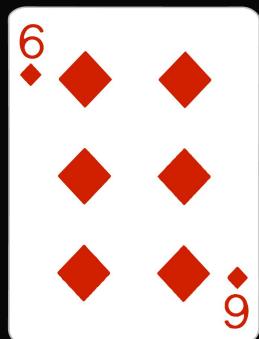
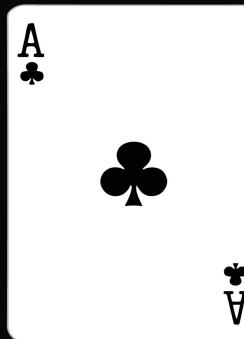
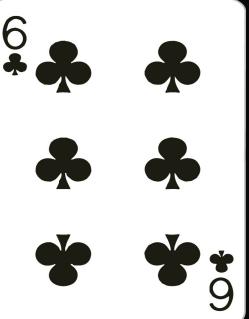
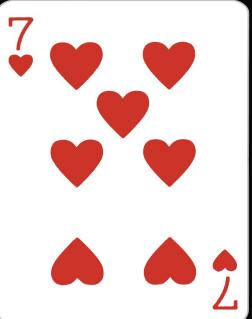
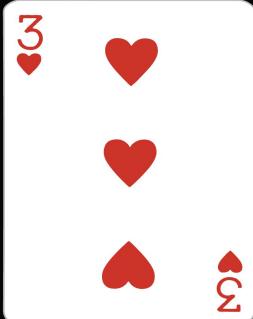


Opponent

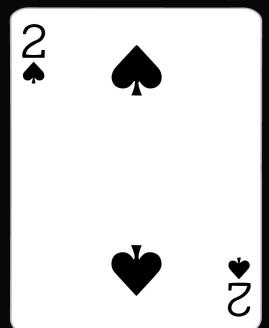


YOU

Suspense through Randomness

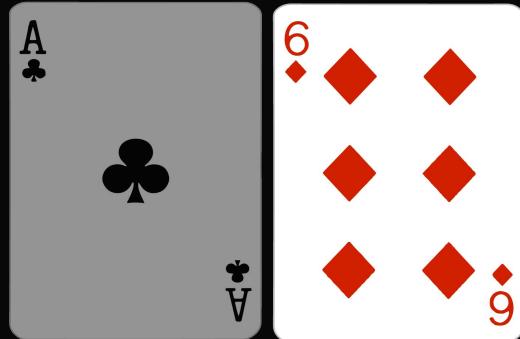
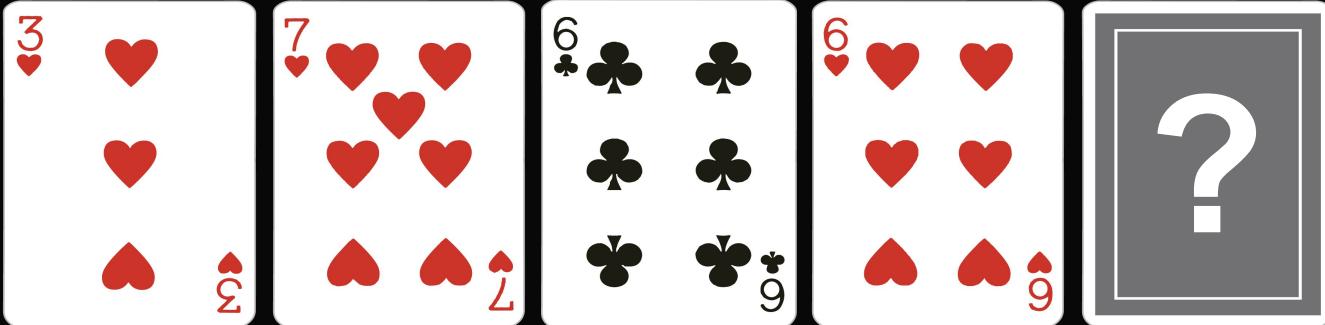


Opponent

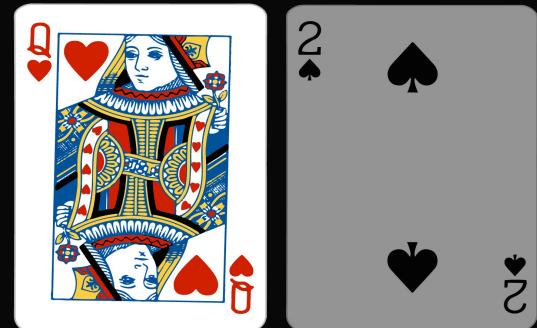


YOU

Suspense through Randomness



Opponent



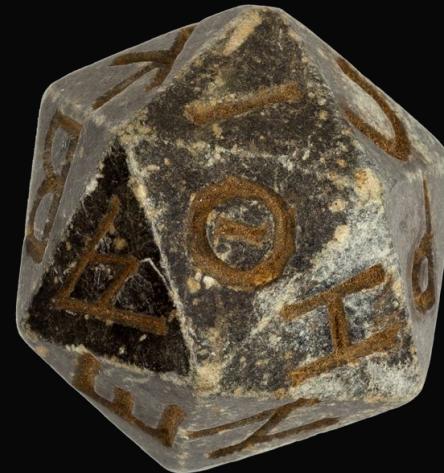
YOU

What Randomness is
How Randomness feels



Randomness in games

- We've used randomness in games since pre-history.
- Relation to divination, fortune-telling, fate
- Deep-seated concept of fairness



Egyptian D20, around 2000 years old

Random Numbers

The computer only knows numbers

- Sequence of numbers
- Independent from each other
- Independent from outside influences

```
function random(min,max) { /*magic*/ }
```



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Cloudflare's lava lamps

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www.fourmilab.ch/hotbits/

Let's make a game



Settlers of Catan

- Euro-style board game
- Limited influence of luck
- But that's today's topic

Uses sum of 2D6.

When a 7 is rolled bad stuff happens.



Picture: catan.com

Settlers of Catan

Really easy to implement.

```
function rollDice()
{
    return random(1,6) + random(1,6);
}
```

Settlers of Catan

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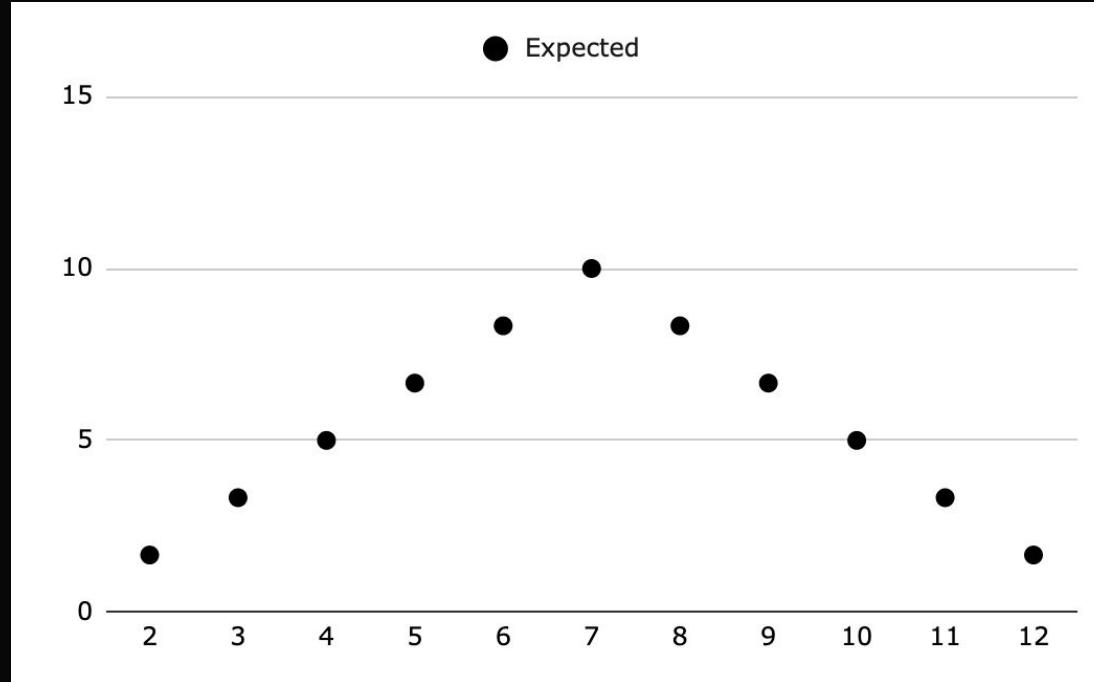
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Cheating???

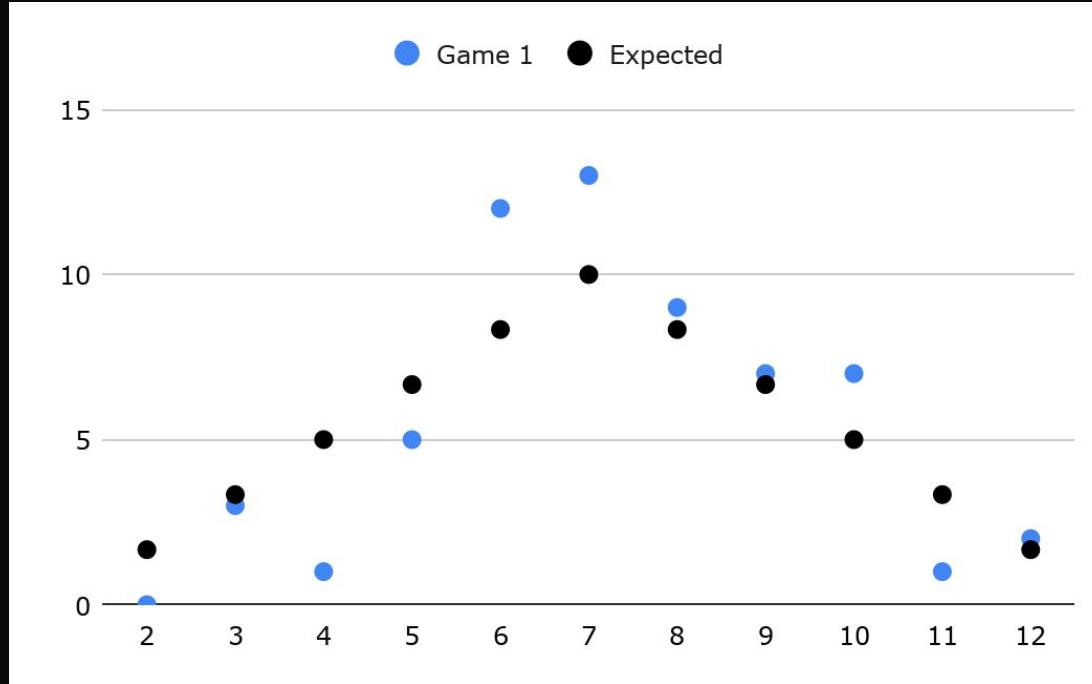
I feel this game's AI simply cheats on harder difficulty levels. For example I shot to a commanding lead, then the dice rolled the number 5 seven times in a row, when I had nothing on a 5 hex. I am starting to see patterns like this. Anyone else or am I crazy?



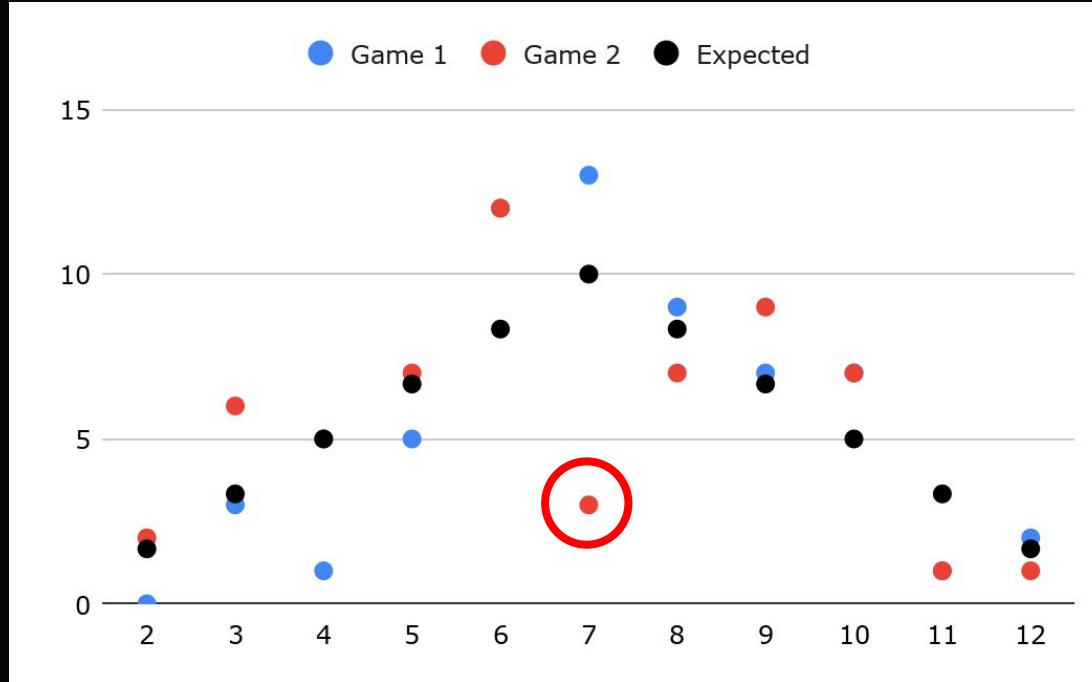
Settlers of Catan



Settlers of Catan



Settlers of Catan



Dice Algorithm Sucks



•  about a year ago

Re: [Dice Rolls Not Random](#)

Alright, I have been playing Catan online for years now and I have never been so disgusted and disappointed by the complete mockery of dice patterns. I have played several games within the past 2 days wherein a 6 or an 8 were not rolled once for at least 3 consecutive barbarian attacks. All the while, 11s and 3s were rolled exhaustively. Such inconsistency with probabilities only favors the poor strategists or the gambler. There needs to be better consistency with the dice mode and the roll patterns.



Dice Algorithm Sucks

N

One confirmed pattern that consistently happened a year ago was this:

9,7,4,5,10,5,7,5,12,4,12,12,10,7,8,7,5,3,7,10,6,6,5,4,5,2,7,9,9,9,9,7,
8,2,9,3,3,9,8,11,9,12,9,8,5,8,6,6,12,3,6,10,3,5,11,2,8,12,4,8,8,10,3,3,5
,6,5,2,5,8,8,9,8,9,5,3,7,6,7,9,8,4,11,9,5...



Dice Algorithm Sucks



Replying to @CatanUniverse

Correct. There's a difference btwn limited probability like dice in the real world and random. Real dice don't roll 10 six turns in a row

5:12 AM - 19 Sep 2017

1



Dice Algorithm Sucks



Replying to @CatanUniverse

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5:12 AM - 19 Sep

1



I'm uninstalling

Cognitive Bias

- Humans are irrational.
- We see patterns everywhere.
- Clustering illusion: Small sample size leads to imagined clusters.
- Gambler's Fallacy: Dice rolls are “hot” or “due”.



The machine is a liar

Physical dice are “dumb”.

But computers are “smart”. They have **agency**.
So we suspect them of cheating.

Especially if there’s a humanoid representation
like the AI opponents.

So? Let’s double down on that!



Catan Universe (2018)

Make Random Less Random



Game Mode: Card Stack

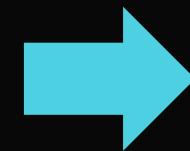


Settlers of Catan (iPhone, 2010)

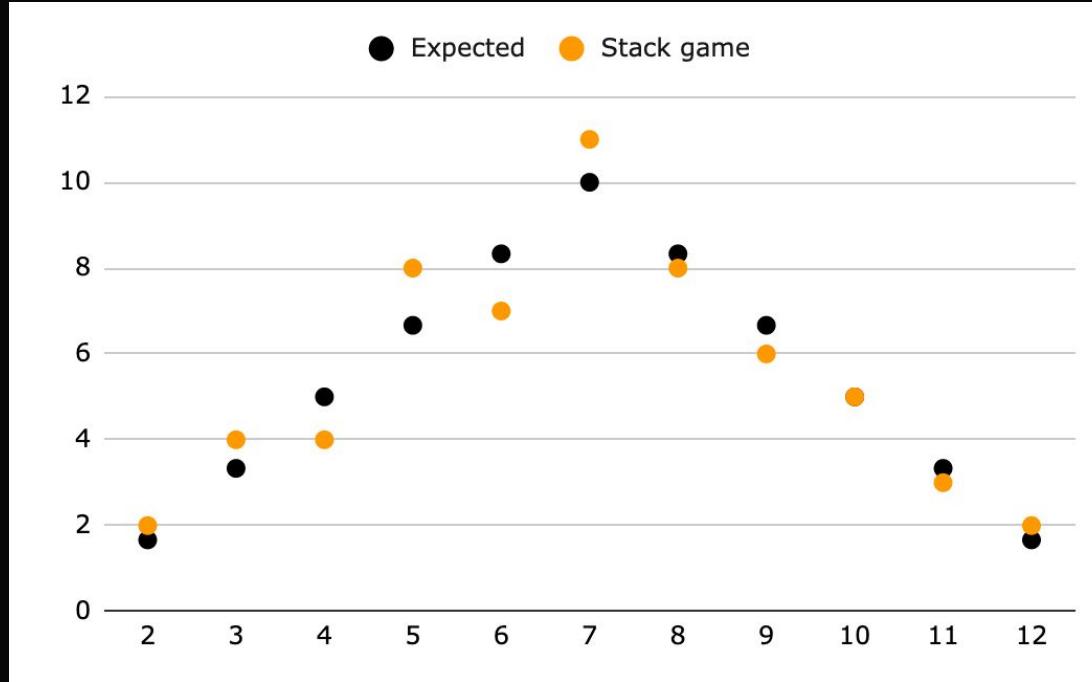


	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10
	6	7	8	9	10	11
	7	8	9	10	11	12

- Take all possible results
- Write them on cards
- Put all cards into a stack
- Shuffle
- To roll: draw a card
- Reshuffle when exhausted



Card Stack



Card Stack RNG

- Deviates much less from “Expected” distribution.
- Not independent from each other!
- We “know” that a die roll comes, just not when.
- Beware card counting.
- Players still question the randomness of the shuffle!



Controlling for high-impact events

- Remember: Rolling a 7 in Catan means bad things.
- Bad things with a face.
- Often named as source of frustration.

Can we control for the high-impact event only without touching the rest of the game?



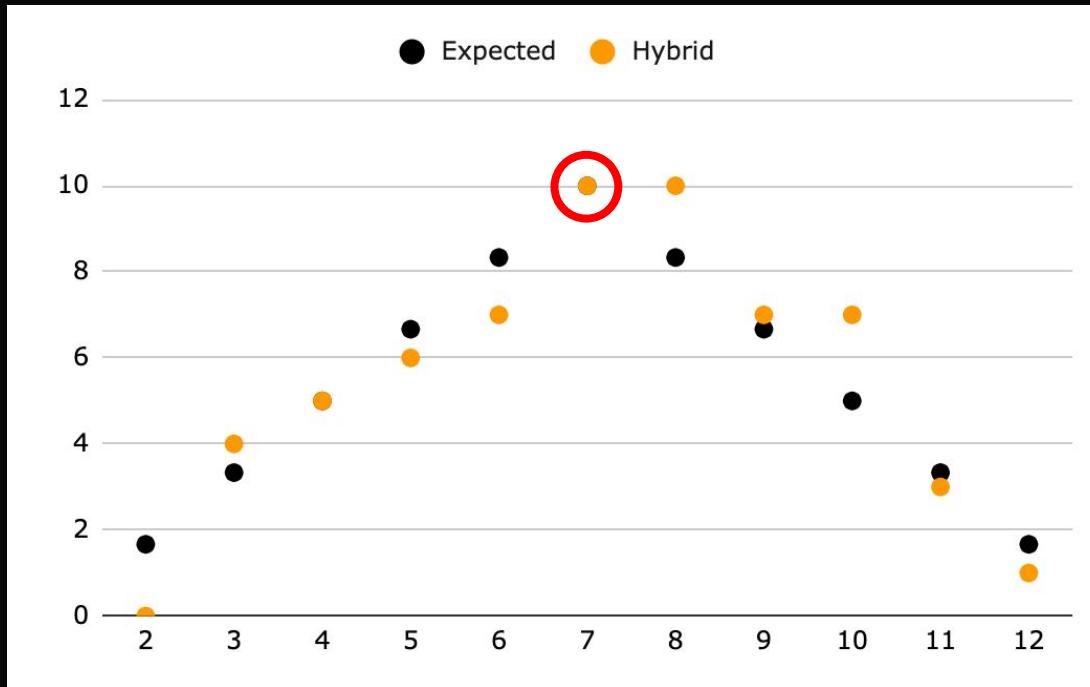
Hybrid approach (Hypothetical)

- Use card stack to determine if it was a 7 (1 out of 6 chance)
- If it was not, roll 2D6 randomly, but exclude 7 as a possible outcome.

```
function roll2d6( )
{
    if (drawSevenFromStack( ))
    {
        return 7;
    } else {
        return roll2d6RandomButNoSeven( );
    }
}
```



Catan: Hybrid approach (Hypothetical)

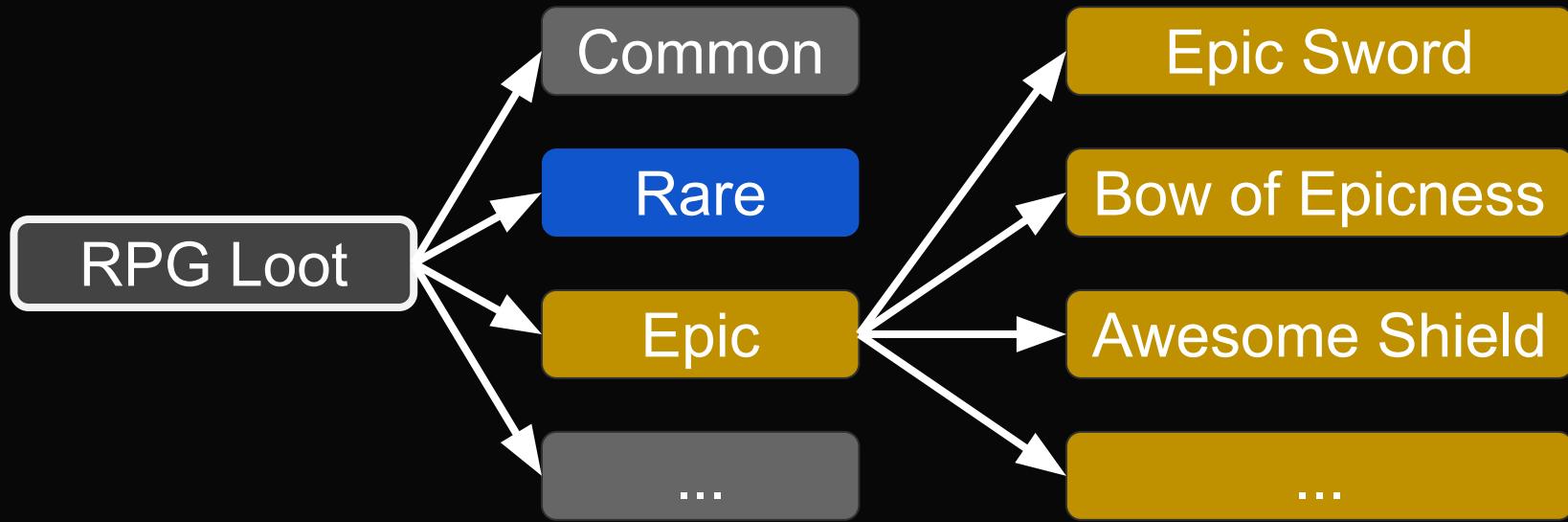


Decision Trees

Using decision trees you can mix and match random processes.



Decision Trees



Single roll with low probability

Example: Chance of Epic loot is 2%

Stack: [Yes,No,No,No,No,No,... (total of 49 No)]

That seems unwieldy.



Briefly: Progressive Randomness

At least as old as Warcraft 3

- Roll against percentage.
- If roll failed, increase percentage.
- After **N** rolls, the chance reaches 100%.

I know at least one game that uses this for its loot boxes.



Sidenote: What's in the box?

A box is impersonal. It has no agency. It offers less projection surface than a human face.

Hypothesis: I have a feeling that players are less prone to suspect a box of cheating.



Image: Diego López

Beyond Shuffling



Recently ...

Hey. We want to generate a lot of levels
for a game.



Recently ...

Hey. We want to generate a lot of levels
for a game.

Okay. What do you have?



Content Generation

5 art sets

17 animal characters

Task: Shouldn't repeat (too much).

Snow



Tropical



Temperate

Desert

... 17 in total

Far East

Content Generation

First idea: Generate all combinations and shuffle.



Is this Zootopia?



Dependencies

Level parameters depend on each other.

By the way: Looks a lot like a decision tree.

Snow:
Polar Bear
Husky
Moose

Temperate:
Pelican
Poodle
Horse
Dachshund

Tropical:
Tiger
Anteater
Crocodile
Koala

Desert:
Serval
Elephant
Lion

Far East:
Panda
Crane



This is getting complicated

- Only generate combinations where dependencies are met.
- With other level parameters (buildings, modifiers, ...) problem space becomes too large to brute-force.



This is getting complicated

- Only generate combinations where dependencies are met.
- With other level parameters (buildings, modifiers, ...) problem space becomes too large to brute-force.

More worryingly, we might still get three levels in a row with the same animal:



Level 118



Level 119



Level 120



Level 121



Level 122

Don't repeat (too much)

What are we trying to achieve here?

- The level sequence should **feel** designed.
- That is: It should not feel random.
- But also not predictable.
- We are fighting the Clustering Illusion.

⇒ Break up clusters, but keep it random.



Constraints

- Theme should only repeat at most every 4 levels
- Animals should only repeat at most every 10 levels
- ...



Constraints

- Theme should only repeat at most every 4 levels
- Animals should only repeat at most every 10 levels
- ...

Idea: Can we pick a **random** level that satisfies these constraints?



(Pseudo) Random Numbers



(Pseudo) Random Numbers

Exercise:

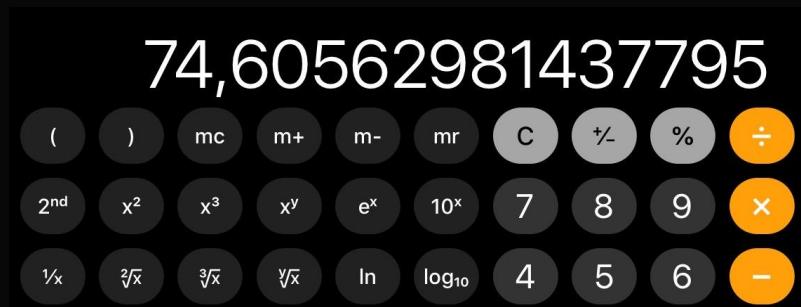
- You need random numbers.
- You only have a smartphone (but no internet).
- Ideas?



Mobile random numbers

Example solution:

- Open the calculator app.
- Punch in some digits (not very random).
- Mash the “square root” button.
- Every time take the last few digits of the result.



Mobile random numbers

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Algorithmic Random Number Generator

1. Start with an initial value. This is called the “seed”.
2. Apply some algorithm.
3. The result is the return value and the seed for the next iteration.

Better algorithm than **sqrt**?

```
uint _state = SEED_VALUE;  
  
uint Random(uint min, uint max) {  
    _state = Algorithm(_state);  
    return min + _state % (max - min);  
}
```



XorShift [Marsaglia, 2003]

- Simple.
- Fast.
- Pretty random.

```
uint Xorshift32(uint input)
{
    var x = input;
    x ^= x << 13;
    x ^= x >> 17;
    x ^= x << 5;
    return x;
}
```



```
GenerateLevel(uint seed)
{
    seed = Xorshift32(seed);
    theme = THEMES[seed % THEMES.Length];

    seed = Xorshift32(seed);
    var animals = ANIMALS_FOR_THEME[theme];
    animal = animals[seed % animals.Length];

    seed = Xorshift32(seed);
    // ... (other parameters)

    return {theme,animal,...}
}
```

Satisfy
dependency



Sampling with constraints

reject



Level 118

reject



Level 119



OK



Generator



Sampling with constraints

Given k levels, find a seed for $k+1$ for which the generated level fits the constraints.

Offline-generated content with one **uint** per level.
Level generation is **O(1)**.

```
uint[] SEEDS = new uint[]  
{  
    347568242,  
    200614631,  
    125880852,  
    1188087749,  
    64214604,  
    1022496923,  
    68040198,  
    1449779801,  
    ...  
}
```

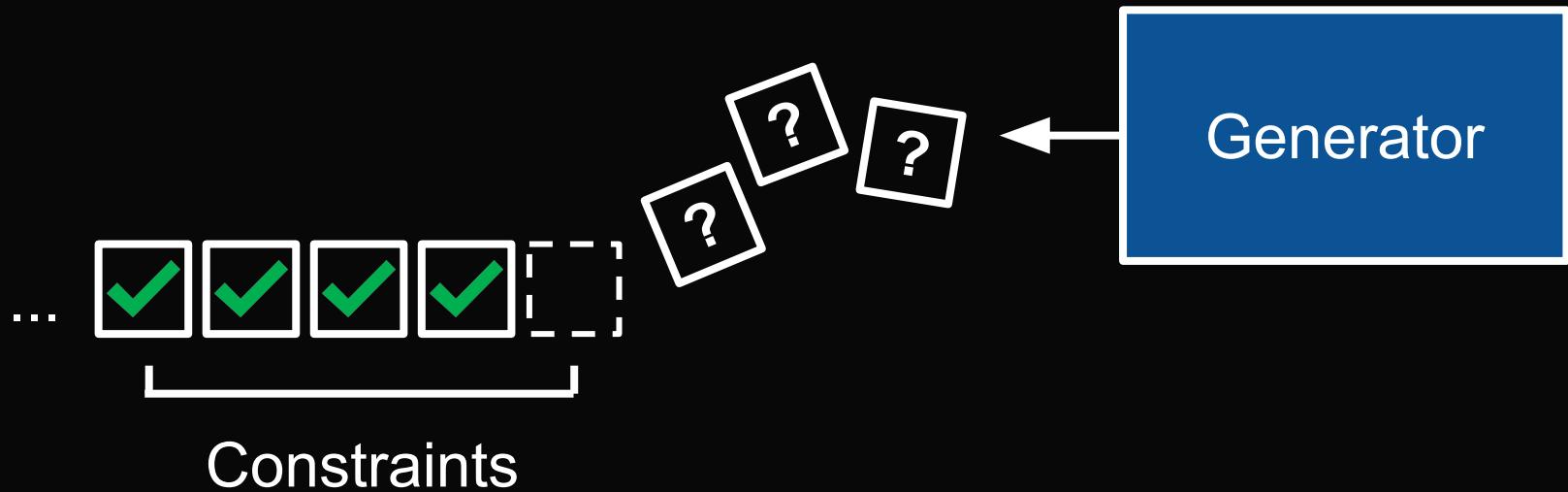


Level Generation Result

- Solves Dependencies (no polar bear in desert)
- Solves Constraints (no two tigers in a row)
- Tiny disk space.
- Fast at runtime.



Sampling with constraints



Sampling with constraints

We can “filter” any random sequence:

- Catan: Discard if player rolled the same value last round.
- Loot Box: Discard not Epic if last 20 boxes were not Epic.
- Match-3 game: Trickle gem colors that are more fun.

Very inefficient, but very flexible.



Summary



“Modern” Randomness

- Increasingly sophisticated.
- Optimized towards a goal (usually revenue).
- Analytics-driven. Outliers are bad!
- We have lots more compute power.



Trust

- Are loot boxes truly random? (Probably not)
 - Is the random encounter in my RPG random?
 - Does my Match-3 game give me useless colors on purpose?

Trust

- Managing player frustration is core part of game design. Can be desired.
- Covenant with the player.
- Gambling law compliance.



Takeaways

- Real randomness often doesn't "feel" random.
- Shuffling, decision trees, Sampling with Constraints, ...
- Presentation matters. A human face gives projection surface.
- Game Design, Psychology and Data Science.

Exciting times to be in the games industry.



Thank You

www.hendrikdemmer.com



Bonus Slides



Fisher-Yates Shuffle

```
function shuffleInPlace(array)
{
    for (var i=0;i<array.length;i++)
    {
        var temp = array[i];
        var j = random(0,i);
        array[i] = array[j];
        array[j] = temp;
    }
}
```



Shuffle algorithm (quick'n'dirty)

```
// works almost always
function shuffleInPlace(array)
{
    array.sort(( ) => Math.random( ) - 0.5);
}
```



Random comparison function

Shuffling large sets

What about very large sets?

- Huge libraries
- Procedurally generated content
- Very large sets might not even fit into main memory
- Indirection may be costly, e.g. shader code



Permutation Polynomials

Need a fast permutation, got a (good) prime?

$$x^5 + ax^3 + 5^{-1}a^2x \text{ (} a \text{ arbitrary)}$$

$$q \equiv \pm 2 \pmod{5}$$

Also exist for powers of two [Rivest, 2000].



Is this more fun?

- Test and measure!
- Are your players gamblers?
- What do you tell them?



Pen and Paper RPG

- Recently been playing this with friends over Discord
- You roll **nD6** and count the number of sixes.
- No sixes means the check failed.
- Frustration is part of the game's design.



Image: frialigan.se

I wrote a bot

gonzoh 07/21/2019
!r 10

wodbot BOT 07/21/2019
@gonzoh, [2,3,2,4,1,5,5,4,4,4] : 0



I wrote a bot

- The highest possible stat is 10.
- And you still fail a lot.
- 16.1% fail chance

Cue the tableflip!

Directed at the bot, not at me.

gonzoh 07/21/2019

!r 10

wodbot BOT 07/21/2019

@gonzoh, [2,3,2,4,1,5,5,4,4,4] : 0



So one day ...

- Use cards: [1,2,3,4,5,6]
- 7 decks (this value is eyeballed)
- Fail chance: 12.7%
- Changed for enemies as well.
- Chance of 10 sixes in 10 throws:
0%

gonzoh 10/09/2019

!r 10

wodbot BOT 10/09/2019

@gonzoh, [4,6,4,3,4,5,3,3,1,4] : 1



So one day ...

The bot looked the same.

I didn't tell the players.

A lot less complaining.



End of Bonus Slides

