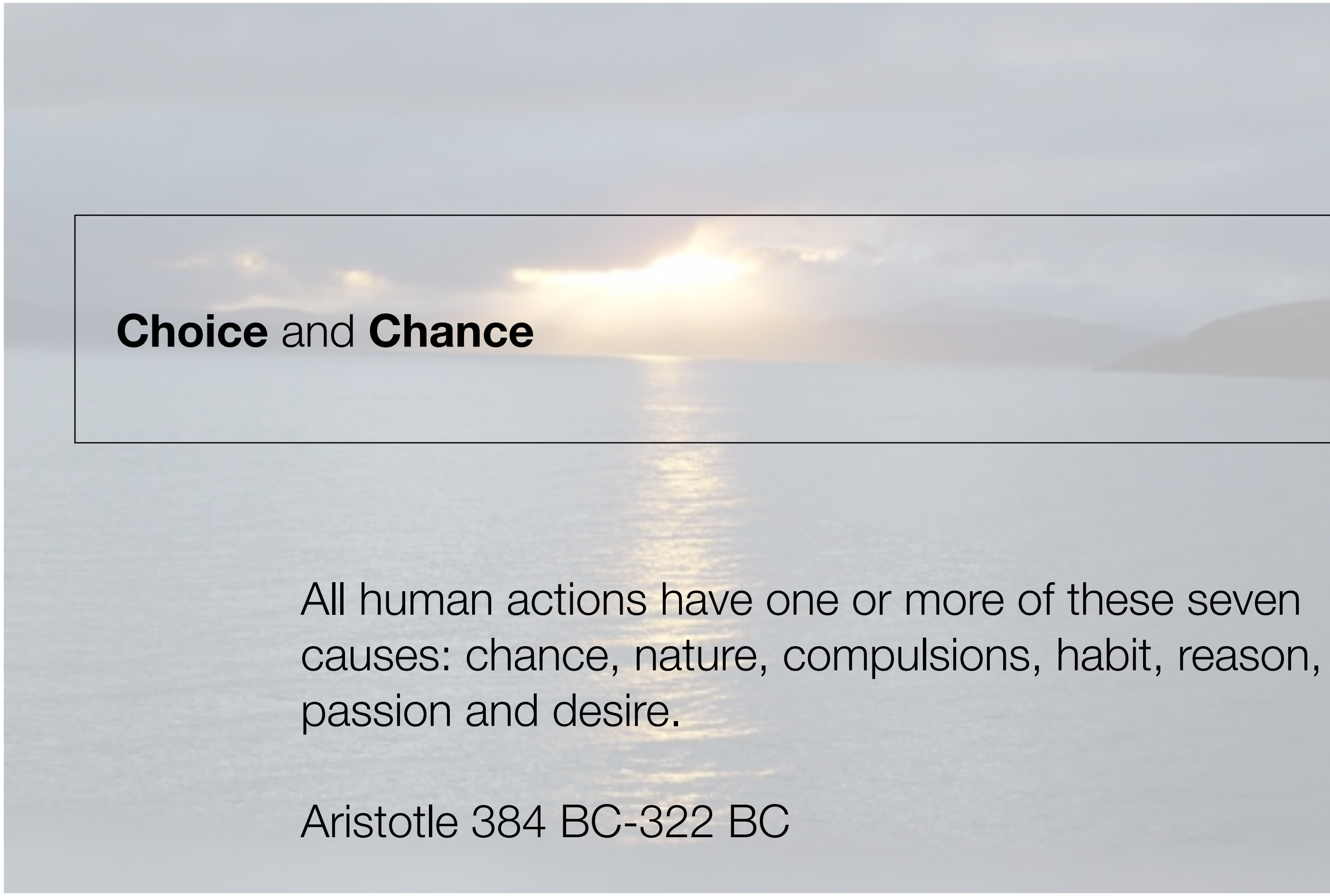


Choice and **Chance**

All human actions have one or more of these seven causes: chance, nature, compulsions, habit, reason, passion and desire.

Aristotle 384 BC-322 BC

Richard Hoadley
2007-9
v02

Note

This presentation is available in pdf format at

rhoadley.org/presentations

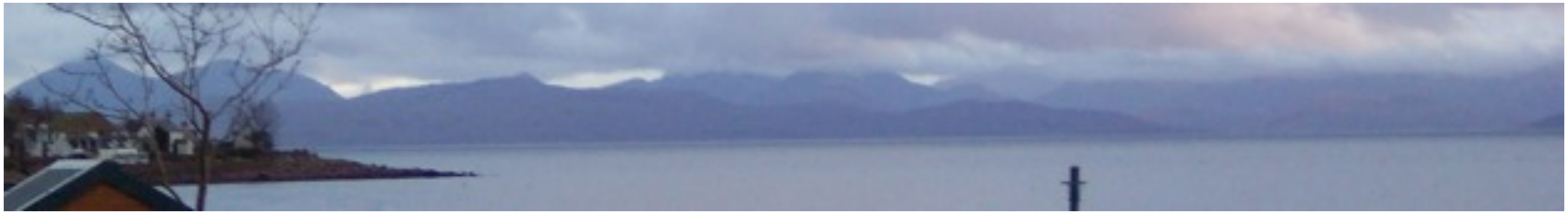
Further information is available at

rhoadley.org

Most of the audio and video examples are available separately on the WebCT implementation of this presentation:

http://webct.anglia.ac.uk/

Hills and Water from Applecross, Scotland, April 2007



Use the lines of the hills in the background

Lots of clear information here

Natural Forms **Dripping Tap**

- Try this with audio - record the sound of a tap that's dripping.
- Then increase the rate until the drips start to come together into a stream.
- This is the point at which you have chaotic behaviour as the tap 'decides' whether it's output should be a drip or a stream.

Natural Forms **American Beauty**

Excerpt from the film **American Beauty (1999)**

Notice the music here. Does this reflect the 'randomness' of the plastic bag at all?

Natural Forms **Waves**

Choice and **Chance**

Natural Forms **Waves**

Natural Forms **Clouds**

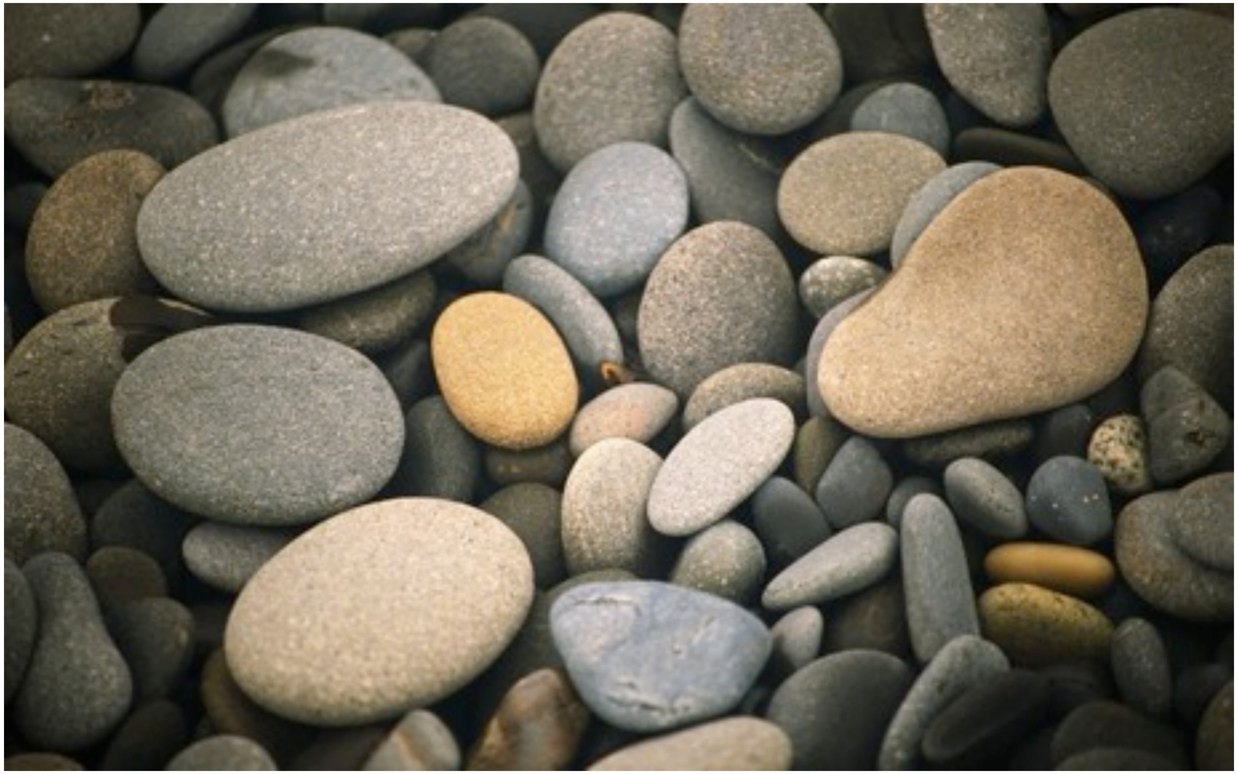
Natural Forms **Clouds**

Natural Forms **Flocks**

Flock

Natural Forms **Pebbles**

Random, and yet patterned. Because we don't expect an explicit pattern, we're not concerned if it's not there. Indeed, any **explicit** patterning would be seen as 'unnatural'.



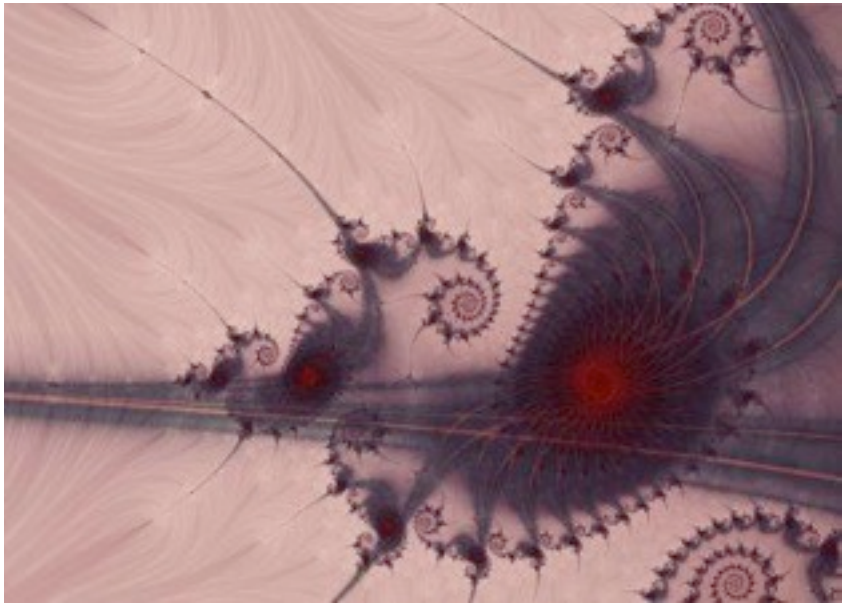
Natural Forms **Leaves**

As pebbles...

Natural and Mathematical Forms **Randomness, Chaos, Fractals and others...**

- Probability theory
- Information Theory
- Entropy
- Algorithmic Randomness
- Algorithmic Probability
- Chaos Theory
- Cryptography
- Game Theory
- Pattern Recognition
- Hidden Variable Theories
- Communication Theory
- Noise

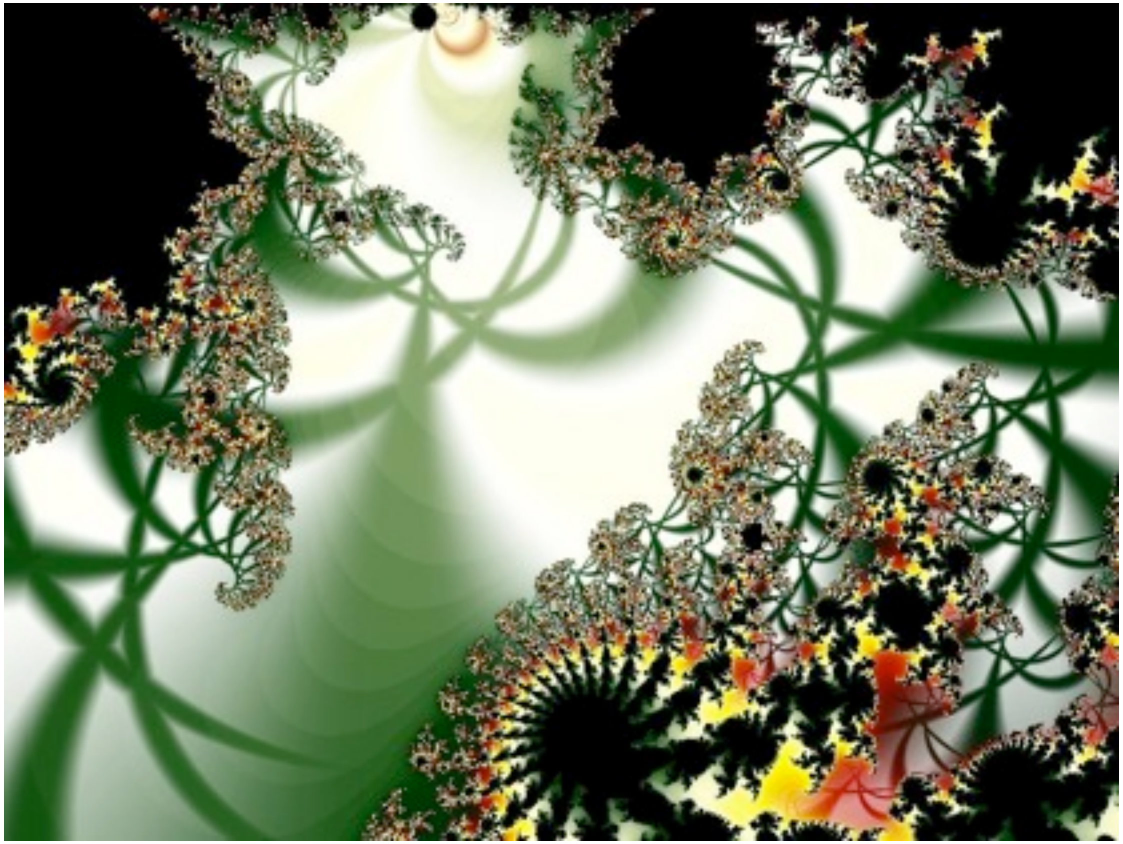
Natural and Mathematical Forms **Images**



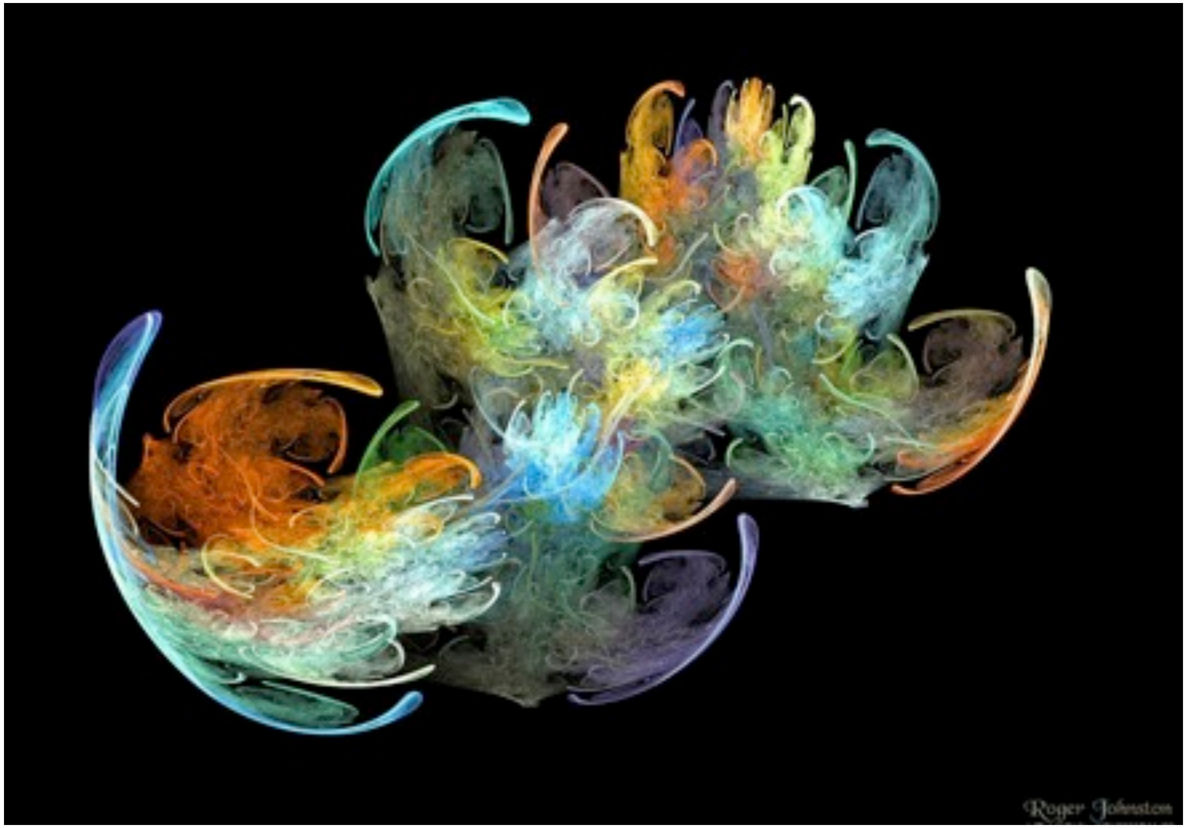
Natural and Mathematical Forms **Fractal Broccoli**

Natural and Mathematical Forms **Fractal Fruit**

Natural and Mathematical Forms **Fractal Garden**

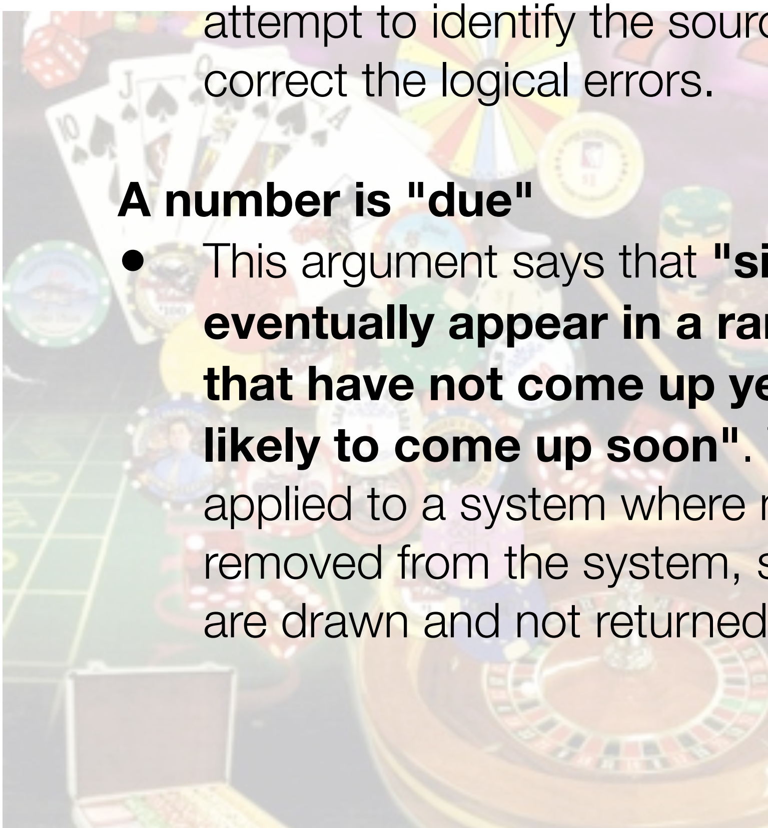


Natural and Mathematical Forms **Fractal Flames**



Game of Life

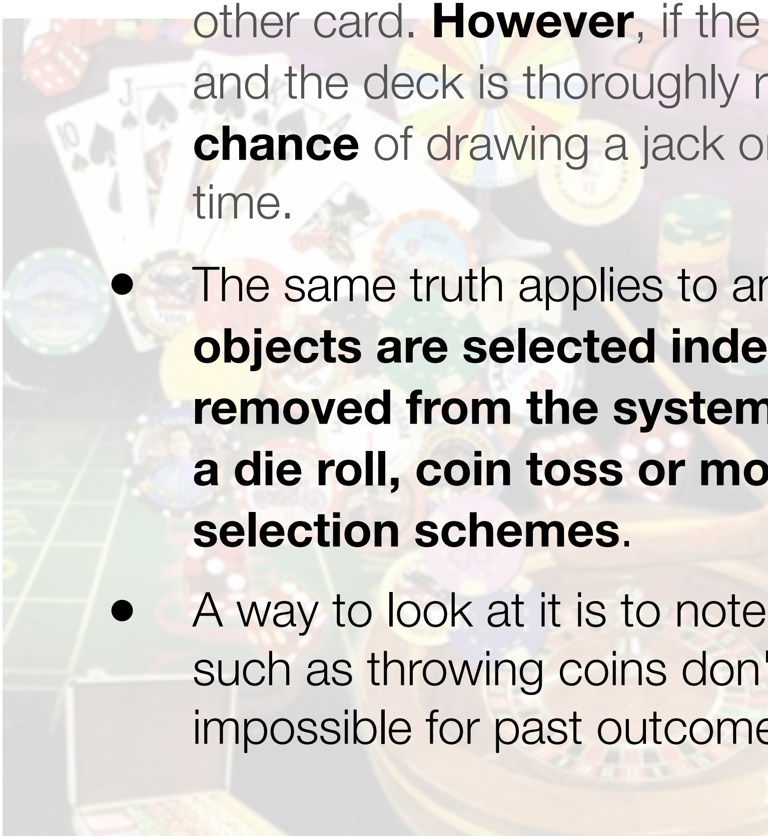
Conway Game of Life



- Popular **perceptions** of **randomness** are **frequently wrong**, based on **logical fallacies**. The following is an attempt to identify the source of such fallacies and correct the logical errors.

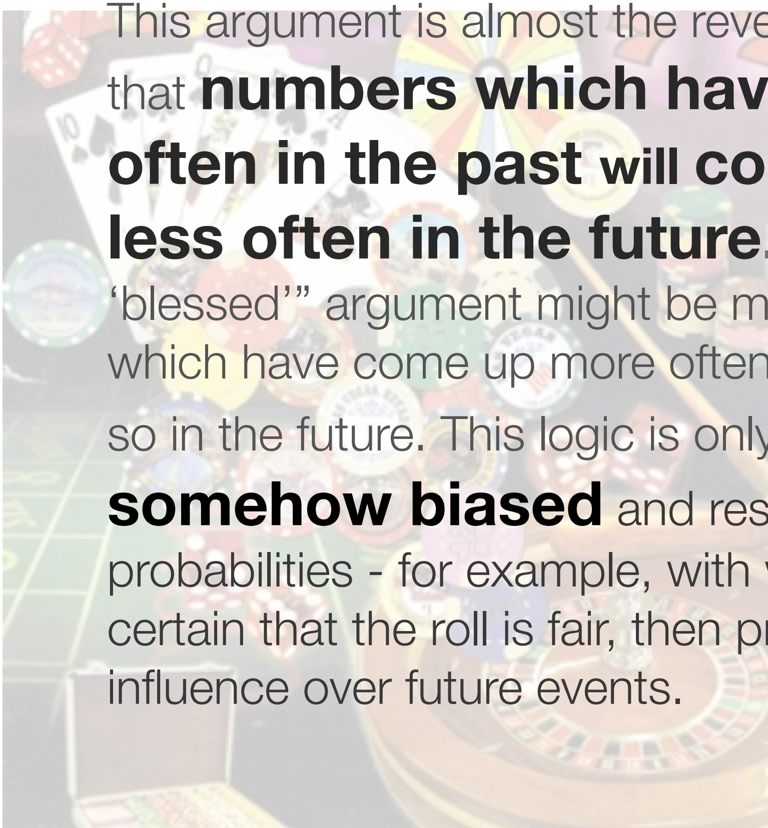
A number is "due"

- This argument says that **"since all numbers will eventually appear in a random selection, those that have not come up yet are 'due' and thus more likely to come up soon"**. This logic is only correct if applied to a system where numbers that come up are removed from the system, such as when playing cards are drawn and not returned to the deck.



- Once a jack is **removed** from the deck, the next draw is **less likely to be a jack** and more likely to be some other card. **However**, if the jack is returned to the deck, and the deck is thoroughly reshuffled, there is an **equal chance** of drawing a jack or any other card the next time.
- The same truth applies to any other case **where objects are selected independently and nothing is removed from the system after each event, such as a die roll, coin toss or most lottery number selection schemes**.
- A way to look at it is to note that random processes such as throwing coins don't have memory, making it impossible for past outcomes to affect the present and

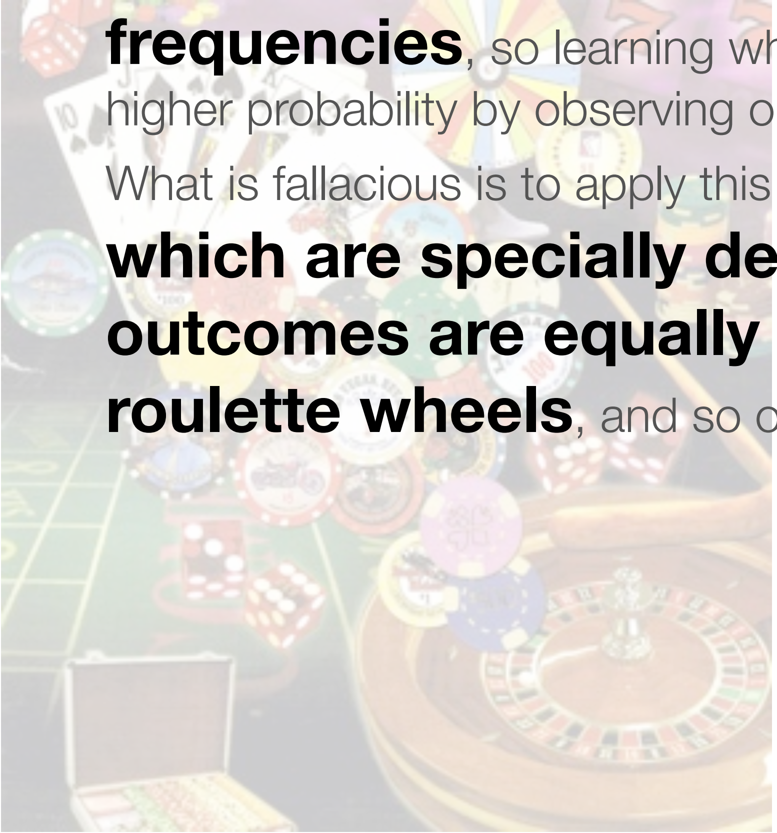
A number is "cursed"



This argument is almost the reverse of the above, and says that **numbers which have come up less often in the past will continue to come up less often in the future**. A similar “number is ‘blessed’” argument might be made saying that numbers which have come up more often in the past are likely to do so in the future. This logic is only **valid** if the **roll is somehow biased** and results don't have equal probabilities - for example, with weighted dice. If we know for certain that the roll is fair, then previous events have no influence over future events.

Note that in **nature**, unexpected or uncertain **events rarely occur with perfectly equal frequencies**, so learning which events are likely to have higher probability by observing outcomes makes sense.

What is fallacious is to apply this logic to **systems which are specially designed so that all outcomes are equally likely** - such as **dice, roulette wheels**, and so on.



Randomness versus **Unpredictability**

- **Randomness** is an **objective property**.
- What **appears random to one observer** may **not** appear random to **another** observer.
- Consider **two observers** of a **sequence of bits**, only one of which who has the cryptographic key needed to turn the sequence of bits into a readable message. **The message is not random**, but is for one of the observers unpredictable.

Randomness versus **Unpredictability**

- One of the intriguing aspects of random processes is that it is hard to know whether the process is truly random. The observer can always **suspect** that there is some "**key**" that **unlocks** the **message**. This is one of the foundations of superstition and is also what is a driving motive, curiosity, for discovery in science and mathematics.

- Under the **cosmological hypothesis** of **determinism** there is **no randomness** in the universe, only **unpredictability**.

Randomness versus **Unpredictability**

- Some **mathematically defined** sequences exhibit some of the same characteristics as **random** sequences, but because they are generated by a describable mechanism they are called **pseudo-random**.

- **Chaotic** systems are **unpredictable** in practice due to their extreme **dependence** on **initial conditions**. Whether or not they are unpredictable in terms of computability theory is a subject of current research. At least in some disciplines of computability theory the notion of randomness turns out to be identified with computational unpredictability.

Randomness versus **Unpredictability**

It is important to remember that the **randomness** of a **phenomenon is not itself random** and can often be **precisely characterised,** usually in terms of probability or expected value. For instance **quantum mechanics** allows a **very precise calculation** of the half-lives of atoms **even though the process** of atomic decay **is a random one**. More simply, though we **cannot predict the outcome of a single toss of a fair coin**, we can **characterise its general behaviour** by saying that if a large number of tosses are made, roughly half of them will show up "Heads". Ohm's law and the kinetic theory of gases are precise characterisations of macroscopic phenomena which are random on the microscopic level.

Chaos and **Chaotic Systems**

- **Mathematical chaos** is a study of **simple systems** that produce **complicated behaviour**.

- This is **perfect** for making **music** on **modular synthesisers**, since we all know interesting music is complicated, but we can't implement very complicated equations with the limited resources of modular synths.

Chaos and **Chaotic Systems**

The **patterns** produced by **chaotic systems** bear some **similarities** to **random noise**, such as we use to make snare drums and so forth, but tend to have much more structure. The chaotic patterns tend to be **“quasi-periodic”**, that is, the output of the system follows a regular pattern, but not exactly.

From cycle to cycle, the patterns are slightly different. Obviously, **totally random noise** is not too **useful** for specifying melodies and rhythms (although some may argue to the contrary). But chaotic patterns seem to have just **the right mix** of **randomness** and **repeatability** to produce **interesting music**.

The first patch we will look at implements four simple non-linear ecosystems, defined by the formula that Mitchell Feigenbaum used to come to his 'Chaos'-theory. The equation that governs this chaotic system is

$$X(t+1) = G * X(t) * (1 - X(t))$$

This equation is known as the **Logistic Equation**. It was first used to model the population of animal species from year to year. In the equation above X(t) is the ratio of the actual population to the maximum population. Each iteration (e.g. from one year to the next) gives the new relative population in terms of the old one.

Chaos and **Chaotic Systems**

$$X(t+1) = G * X(t) * (1 - X(t))$$

The parameter G is the effective growth rate. The two terms in the equations model the fact that more animals will have more offspring (so growth is proportional to X), but will compete for resources (so that growth is also proportional to (1-X)). As the population increases the load on the environment increases reducing the availability of resources and limiting the growth rate.

Chaos and **Chaotic Systems**

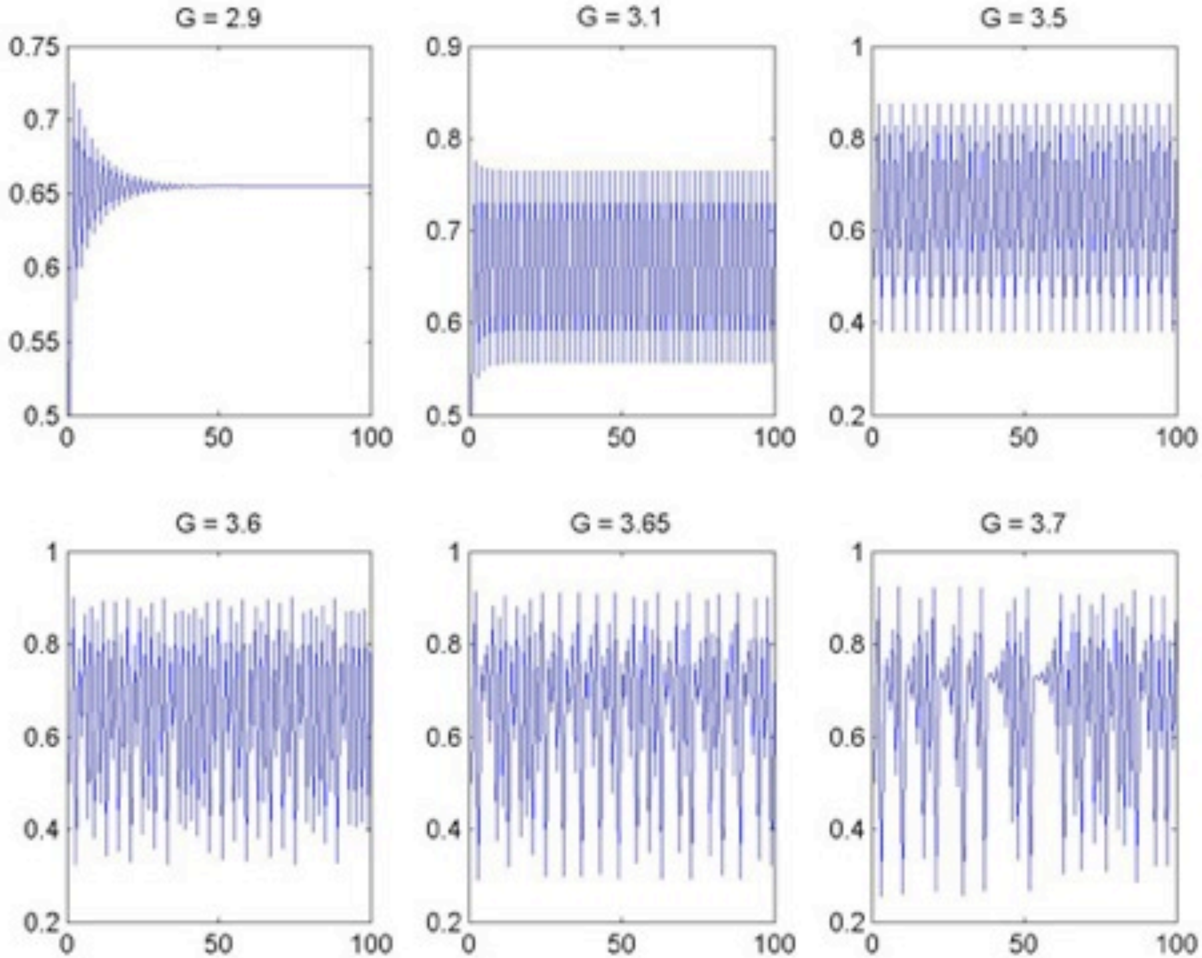
This is modeled by the (1-X(t)) term. For growth rates G less than 1, X(t) tends to 0. For growth rates between 1 and 3, X(t) tends to 1 - 1/G. Beyond G=3 a bifurcation occurs causing an oscillation from year to year. (corresponding to high and low populations in alternate years). Further bifurcations occur until at G = 3.53... chaotic dynamics set in. For values of G greater than 4 the system diverges (goes off to -infinity, or saturates at the most negative possible value).

Chaos and **Chaotic Systems**

What does all this animal husbandry have to do with the dog-eat-dog world of musical synthesis? Well, the chaotic behaviour exhibited by the logistic function can be used to produce interesting music. In the patch below the X values are used to play notes, but they could be used to control anything. In the patch there are four separate chaotic systems implemented. The systems can influence each other. They can be helped by their right neighbours to become more alive while their growth can be suppressed by their left neighbours. Sounds like real life, don't it? Well, actually it sounds like the Nord Modular, so don't worry, no need for peace keeping forces in your machine. Some settings can make all four systems slowly succumb, others can result in chaotic behaviour, and somewhere in between there should be "easy livin'". In figure 10.1 we show the behaviour of the logistic equation for various settings of the G parameter.

Chaos and **Chaotic Systems**

The behaviour of the logistic equation for various settings of the G parameter. For G less than 3, the system quickly settles to a fixed value. For G between 3 and 3.53 oscillations occur. For G greater than 3.53 chaotic dynamics result.



Chaos and **Chaotic Systems**

For the equation to work it can not start with a zero value for X, as nothing can grow out of nothing unless some "Act of God" is involved. So a provision is made that a small value is automatically added to X, only in the first cycle when X is zero due to patch loading conditions.

Chaos and **Chaotic** Systems

The following patch implements another type of Chaotic system, this one termed the Henon strange attractor. This system was discovered by the French astronomer Michel Henon while studying the dynamics of stars moving within galaxies. The equations for this system are:

x(n+1) = 1 + y(n) - a*x(n)*x(n)
y(n+1) = b*x(n)

The Henon system is 2-dimensional, unlike the logistic system described earlier, which was 1-dimensional. That means it produces two values which you can use to control various aspects of the music. As with the logistic equation, certain settings of the parameters a and b give rise to chaotic behaviour. An example is shown in figure 10.3, which plots the values of x and y for a setting of a=1.4, b=0.3. Notice that the points are distributed along a smooth curve, so that overall pattern of the values of x and y is appears non-random, and repeatable. At any given time, however, the values are essentially randomly distributed along this curve. Thus we have a "structured randomness", just the thing we are looking for in algorithmic music!

Art

Brief overview

William Burroughs and Brion Gysin

Brief overview

BBC Documentary about William Burroughs: “Nothing is True, Everything is Permitted”

Brion Gysin and William S. Burroughs - Rub Out The World (1965)

Art

Cage

Tudor

Mysticism

Chaos/Cosmos

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