Thanos Was Bad At Maths:Why The Snap Was Mathematically Doomed

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1 The Snap

One snap, half of all life gone. But could there have been a different story if Thanos had consulted with a mathematician? Thanos believed that resources are finite and that if life was left unchecked, it would cease to exist. He had seen it happen on Titan, his home, and when he proposed a random killing of the population he was exiled. But his prophecy was right, Titan was destroyed leaving behind a ruined landscape. But what if I told you that I could prove Thanos' solution wrong and that there was truly no fix to all of this using only the power of exponential growth and a model to simulate population growth called the Logistic Model.

2 How does Growth Work

Before we can critique Mad Titan's thinking, we must first understand it.

Let us consider the instant after the snap, half of Earth's population is gone but that means there is half of Earth's population who are alive and can reproduce to have children. When those children are old enough, they will reproduce and have more children. 2 turns to 4 to 8 to 16. The famous English economist Thomas Malthus stated that population growth is not linear but geometric, each extra person is not just an addition to the population but a multiplier of it.

So, this poses the question, if the population grows quicker with each extra person, how long would it take for Earth to recover after the snap?

3 The Maths of the Snap

Now in reality, population growth does not occur in neat generational jumps. But on large scales, like billions of people, growth is spread at almost every moment of every day, which allows us to approximate it using a continuous model.

$$P(t) = P_0 e^{rt}$$

Here $e \approx 2.718$ is not just any random number but a mathematical constant similar to π. Consider e as the number used when continuous growth wants to be represented.Along side that we also have P_0 which is the starting population, **r** the reproductive rate and **t** the time in years.

To measure population growth, we do not measure population size, but how fast a population grows in a given time. This can be written as $\frac{dP}{dt}$ which tells you the rate of growth similar to how a speedometer in a car tells you how fast it is going.

To derive it, we differentiate the continuous model with respect to time (how to find the rate of change).

$$\frac{d}{dt}(P(t)) = \frac{d}{dt}(P_0 e^{rt})$$

$$\frac{dP}{dt} = rP_o e^{rt}$$

The derivative of P(t) is just $\frac{dP}{dt}$ or the rate of change of growth and the right hand side differentiates to $rP_0 e^{rt}$

Finally we know $P_0 e^{rt}$ is just $P(t)$ or the population so we can replace it in the formula with P:

$$\frac{dP}{dt} = rP$$

Or in simpler terms, the growth rate at any instant is proportional to the population size at that time.So a larger population leads to a greater growth rate which leads to a bigger population, perfectly mirroring that compounding behavior of e.

Now with this knowledge, we can answer the question I posed before. How long would it take for the population to recover after the snap?

We want to find the time t when the population is equal to twice the initial population, this will get us back to the full population before the snap.

P(t) = $2P_0$

Now using the equation earlier we can replace P(t) with the exponential model, P_0e^{rt} :

P_0e^{rt} =$2P_0$

Dividing by P_0 on both sides

e^{rt}=2

Taking the natural log of both sides (the inverse operation of e just like the square root is the inverse to squaring)

$rt = ln(2)$

Finally dividing by r on both sides

$$t = \frac{ln(2)}{r}$$

In the MCU the snap took place in 2018 where the growth rate of earth would have been around 0.011. Plugging that into the equation gives us a time to return back to the original population size of 63 years. In 2018 the population was 7,729,902,781 in 1973 it was 3,920,805,042. In the space of 45 years earth had doubled its population, even quicker than predicted.

So Thanos had battled Earth's mightiest heroes to wipe half the life from the universe, just for life on earth to bounce back in one human lifetime. But is this the full story or just another trick from the reality stone?

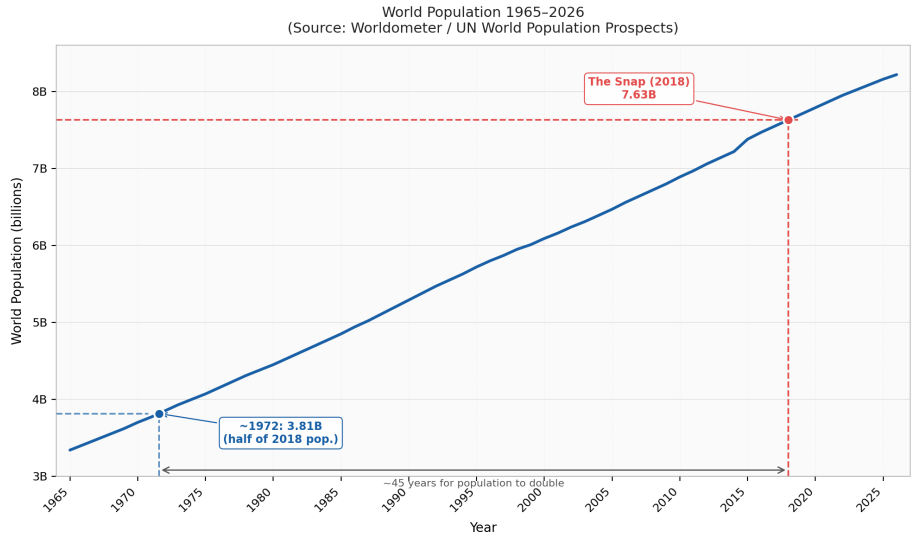

Figure 1: Population Of Earth

4 The Huge Flaw

Look at this exponential curve, what is one thing you notice?

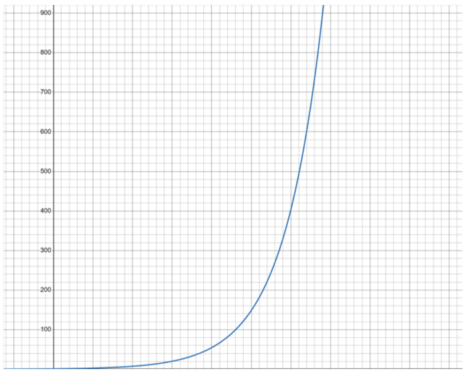

Figure 2: Graph of $y = e^x$ sketched on Desmos

The main flaw of the exponential model when modelling population growth is that it grows infinitely, as long as time flows forward, the population will. However, in the real world this is not true, the resources required for growth dont grow infinitely too. The exponential model does not respect reality, which for some approximations may be appropriate, but if we want to solve this problem, we do.

In Infinity war, Thanos talks about how he watched his planet Titan collapse when the population reached a size it could no longer support, turning it into the wasteland in the movie. This has a mathematical name, carrying capacity, the maximum sustainable population size of a species an environment can support.

Now, looking back to our previous equation, we stated that the growth rate is proportional to the population size. But now taking in all the physical constraints, we want a model that is also proportional to how many resources available.

If K (carrying capacity) is the maximum sustainable population and P is the current population then the proportion of carrying capacity used up is $\frac{P}{K}$. Therefore the remaining carrying capacity can be written as 1-$\frac{P}{K}$ which can be considered as the proportion of unused resources.

$$1 - \frac{P}{K} \leq 1$$

This is always less than or equal to 1 as $\frac{P}{K}$ is always positive. When P is small resources are abundant so the whole expression is close to 1.

$$1 - \frac{1}{10000} = 0.9999$$

When P is not too large but not too small there are spare resources and so growth will occur at a steady rate

$$1 - \frac{5000}{10000} = 0.5000$$

And when P is large resources are scarce so the whole expression is close to 0.

$$1 - \frac{9999}{10000} = 0.0001$$

And in the extreme case when the population is larger than the carrying capacity there will be no spare resources so the growth rate will become negative leading to collapse.

$$1 - \frac{11000}{10000} = \text{-}0.1000$$

This bit of ingenuity acts as the perfect bottleneck for the growth factor. If the population grows too large the expression will approach 0 stopping all growth, and if the population is small the expression will approach 1 allowing the exponential model to do all the work.

Therefore our new equation,known as the logistic model is:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right)$$

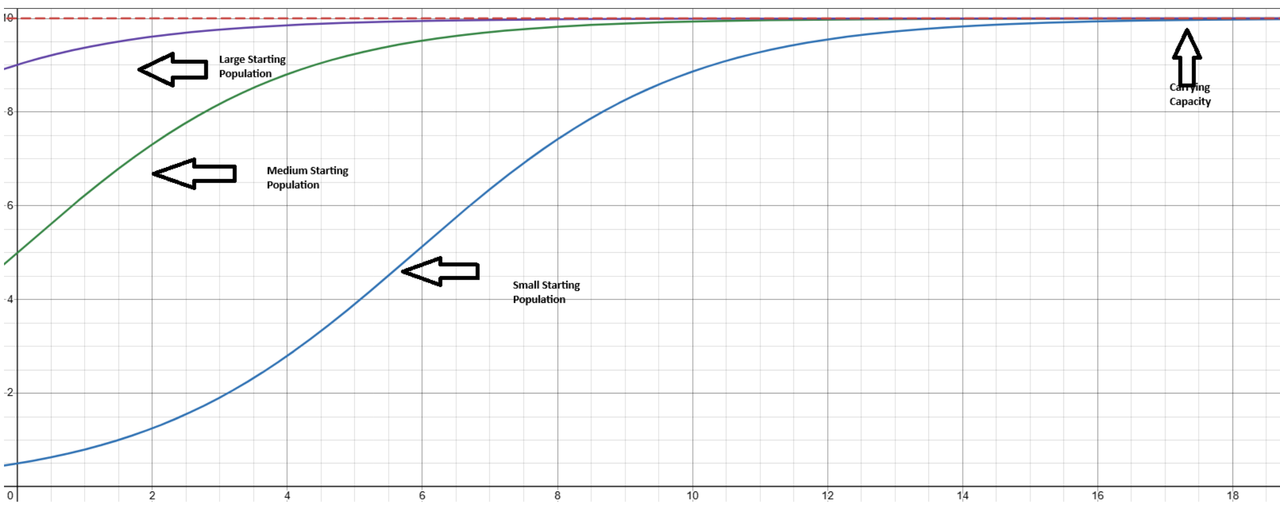

Figure 3: Logistic Curves representing small, medium and large populations and their carrying capacity

The curves tell the same story in a different way, no matter where you start the population will always approach the carrying capacity of it. Like how gravity attracts, the carrying capacity does the same. The small population bursts out the gates before slowly plateauing, the medium population races during the middle, and the large population runs out of breath before the race even begins.

The top curve represents Titan, a planet close to its carrying capacity. When the population exceeds the carrying capacity,the growth rate becomes negative and the population starts to collapse, exactly what happened on Titan. So maybe without knowing the math, Thanos still knew the fate awaiting Titan. However, the solution was far from the right one.

5 Snap, Crackle, Pop

So now we know the logistic model and how carrying capacity works, we can apply this logic to the snap to see the overall effect not just on Earth, but the universe.

Disclaimer: This section will make many assumptions about life in the Marvel Universe for example I do not know the carrying capacity of the alien races, aswell as the population of them or what their reproductive rate is so we will be applying earths statistics. However this argument holds for any species with a positive growth rate.

Thanos was worried about overpopulation and overuse of resources, so lets assume the universe was close to its carrying capacity, lets say $P = 0.8K$

Lets call $1 - \dfrac{P}{K}$ the bottleneck and so it is equal to:

$$1 - \frac{0.8K}{K}$$

$$1 - 0.8 = 0.2$$

We can now plug the bottleneck into the logistic model to find out the rate of growth pre-snap:

$$\frac{dP}{dt} = rP(1 - \frac{P}{K})$$

$$\frac{dP}{dt} = 0.2rP$$

And remember $P = 0.8K$ leaving us with

$$\frac{dP}{dt} = 0.16rK$$

Now after the snap half the life has disappeared, so P will be equal to half of the population before the snap or $0.4K$.

$$1 - \frac{P}{K} = 1 - 0.4 = 0.6$$

$$\frac{dP}{dt} = 0.6rP$$

And subbing in $P = 0.4K$

$$\frac{dP}{dt} = 0.24rK$$

Now if we divide the 2 growth rates we can see how the snap affected it.

$$\frac{0.24rK}{0.16rK} = 1.5$$

So the growth rate after the snap is 1.5 times greater than before the snap. But to see the full extent we need to be able to track the population size at any given moment in time. This is where the logistic solution comes in.

$$P(t) = \frac{K}{1 + Ae^{-rt}}$$

r is the growth rate which is 0.011 on Earth

One thing to note about this formula is that as $t \to \infty$ Ae^{-rt} approaches 0 so the whole fraction approaches $\frac{K}{1}$ or just K which shows us how K is always the destination for the population no matter what.

$$A = \frac{K - P_0}{P_0}$$

This constant A measures how far the initial Population, P_0, is from the carrying capacity. A good analogy to understanding the use of A is thinking about A as a spring and K being the equilibrium, the further away the spring is pulled from the equilibrium the faster it snaps back and the closer to the equilibrium the slower it does.

We can now calculate the A values for both before and after the snap:

Pre Snap:

$$A = \frac{K - 0.8K}{0.8K} = 0.25$$

Post Snap:

$$A = \frac{K - 0.4K}{0.4K} = 1.5$$

Coincidentally this matches our growth rate after the snap however this is just for the specific starting value of $0.8K$.

To see precisely the effect of the snap now, we can track how long it would take both universes to reach $0.99K$. We cannot use K as the curve never actually reaches Kas Ae^{-rt} never actually reaches 0.

Pre Snap Universe:

$$0.99K = \frac{K}{1 + 0.25e^{-0.011t}}$$

$$1 + 0.25e^{-0.011t} = \frac{1}{0.99}$$

$$0.25e^{-0.011t} = 0.0101$$

$$e^{-0.011t} = 0.0404$$

$-0.011t = ln(0.0404)$

$t = 291.7$

So for the Pre Snap Universe it would take 292 years to reach 0.99 of the carrying capacity, but how about the post snap universe?

$$0.99K = \frac{K}{1 + 1.5e^{-0.011t}}$$

$$1 + 1.5e^{-0.011t} = \frac{1}{0.99}$$

$$1.5e^{-0.011t} = 0.0101$$

$$e^{-0.011t} = 0.0067$$

$$-0.011t = ln(0.0067)$$

$$t = 454.6$$

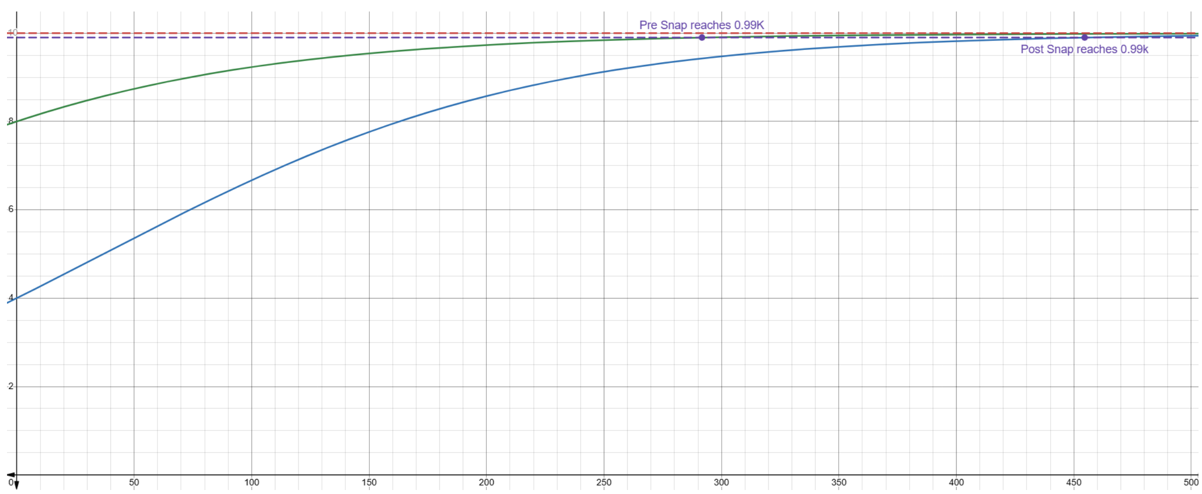

Figure 4: Pre Snap vs Post snap Population Time Graph

So for the Post snap universe it takes 455 years to reach 0.99 of the carrying capacity which is 163 years more than before the snap. Thanos had conquered planets, collected 6 infinity stones and battled the mightiest heroes to save 163 years, nothing.Not even the powers of infinity could defeat the power of mathematics baked into the cosmos.

6 The Mathematical Titan

Maybe Thanos should have wished for a maths textbook, or infinite wisdom. But if Thanos truly wanted to solve overpopulation, what should he have done?

If we look back at our Logistic Model from earlier there are 3 parameters:

$$\frac{dP}{dt} = \mathbf{rP}(1 - \frac{\mathbf{P}}{\mathbf{K}})$$

We've seen how no matter what you do to P it always bounces back but what about the other 2.

Firstly he could have increased K, using the space stone he could have increased the amount of resources in the universe which provides a more sustainable solution. In the Logistic Model if you double K you double the maximum sustainable population forever acting as a ceiling raiser for the universe.

Also he could have decreased r for every species, using the reality stone. This would slow down every population tremendously as this value appears in the exponential term in the logistic solution so it compounds across every generation simultaneously ensuring the population never bounces back.

By combining both of these things Thanos would have got everything he wished for.

$$0.99 \times 2K = \frac{2K}{1 + 1.5e^{-0.0055t}}$$

$$1 + 1.5e^{-0.0055t} = \frac{1}{0.99}$$

$$1.5e^{-0.0055t} = 0.0101$$

$$e^{-0.0055t} = 0.0067$$

$$-0.0055t = ln(0.0067)$$

$$t = 909.2$$

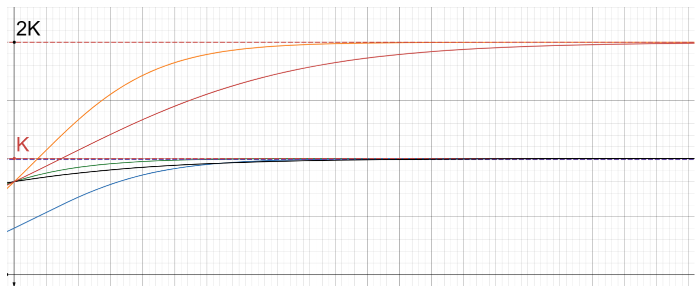

Figure 5: Green: Pre Snap Curve - Blue: Post Snap Curve - Black: Halving reproductive rate - Red: Doubling carrying capacity and halving reproductive rate - Orange: Doubling carrying capacity

And this is only some of the possibilities of what he could have done, with the power of the 6 infinity stones Thanos could have slowed down reproduction or increased resources to his liking. Thanos had the power to save the universe, but he lacked the wisdom to do it.

7 Endgame

The exponential model told us the snap would be undone in 63 years. The logistic model said 163 years while increasing the growth rate by 1.5x. And by altering both the K and r values could have bought 909 years in a reasonable way. Thanos' diagnosis was not wrong, just like Titan, the universe was reaching its carrying capacity and a dark fate awaited, but his solution was. He changed the one parameter which always bounced back, and paid with his life. 6 infinity stones, but one conclusion. No gauntlet can snap away the laws of mathematics.