The Math of Human Population Growth and CO2 Emissions

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In a paper published in the Science magazine in 1960, von Foerster et al. argued that human population growth follows a hyperbolic pattern with a singularity in the year 2026. Using current empirical data from 10,000 BCE to 2023 CE, we re-examine this claim. We find that human population initially grew exponentially as $N(t)$ $e^{t/T}$ with T 3000 years. This growth then gradually evolved to be super-exponential with a form similar to the Bose function in statistical physics. Population growth further accelerated around 1700, entering the hyperbolic regime $N(t) = C/(t_s - t)$ with the extrapolated singularity year $t_s = 2030$, which is close to the prediction by von Foerster et al.

We attribute the switch from the super-exponential to the hyperbolic regime to the onset of the Industrial Revolution and the transition to massive use of fossil fuels. This claim is supported by a linear relation that we find between population and the increase in the atmospheric level of CO2 from 1700 to 2000. But in the 21st century, we observe that the inverse population curve $1/N(t)$ deviates from a straight line and follows a pattern of *avoided crossing* described by the square root of the Lorentzian function. As a result, the singularity transforms into a peak in human population at $t_s = 2030$ of the time width $\tau = 32$ years. We also find that the increase in the atmospheric CO2 level since 1700 is well fitted by $\mathrm{arccot}[(t_s - t)/\tau_F]$ with $\tau_F = 40$ years, which implies a peak in the annual CO2 emissions at the same year $t_s = 2030$.

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Video recording: `https://www.youtube.com/watch?v=kJPFApdokrg`