Some remarkably universal empirical formulas are used to characterize the slow dynamics of biological systems and disordered materials. Stretched-exponential relaxation has been used since 1854 for time-dependent response, non-classical critical scaling has been used since 1893 for temperature-dependent behavior, and 1/f noise has been used since 1925 for frequency-dependent fluctuations. I will describe a common physical foundation for all of these formulas. The ideas are based on “nanothermodynamics,” where local thermal effects are included in treating nanometer-sized fluctuations inside complex systems. The mechanism may be attributed to strict adherence to the laws of thermodynamics: non-extensive energy is conserved by including Hill’s subdivision potential, and maximum entropy is maintained by coupling to a finite thermal bath. Alternatively the mechanism may involve information theory for reversible fluctuations, or the statistics of indistinguishable particles for identical states. I will emphasize how theoretical models and computer simulations based on these ideas yield the empirical formulas, plus deviations from the formulas that often match measured behavior.