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The Fractional Macro Evolution Model: A simple quantitative scaling macroevolution model

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Scaling fluctuation analyses of the marine animal diversity, extinction and origination rates based on the Paleobiology Database occurrence data have opened new perspectives on macroevolution, supporting the hypothesis that the environment (climate proxies) and life (extinction and origination rates) are scaling over the "megaclimate" biogeological regime (from ≈ 1 Myr to at least 400Myrs). In the emerging picture, biodiversity is a scaling "cross-over" phenomenon being dominated by the environment at short time scales and by life at long times scales with a cross-over at ≈40Myrs. These findings provide the empirical basis for constructing the Fractional MacroEvolution Model (FMEM), a simple stochastic model combining destabilizing and stabilizing tendencies in macroevolutionary dynamics. The FMEM is driven by two scaling processes: temperature and turnover rates.

Macroevolution models are typically deterministic (albeit sometimes perturbed by random noises), and based on integer ordered differential equations. In contrast, the FMEM is stochastic and based on fractional ordered equations. Stochastic models are natural for systems with large numbers of degrees of freedom and fractional equations naturally give rise to scaling processes.

The basic FMEM drivers are fractional Brownian motions (temperature, *T*) and fractional Gaussian noises (turnover rates E_+) and the responses (solutions), are fractionally integrated fractional Relaxation processes (diversity (*D*), extinction (*E*), origination (O) and $E_- = O - E$). We discuss the impulse response (itself a model for impulse perturbations such as bolide impacts) and derive the full statistical properties including cross covariances. By numerically solving the model, we verified the mathematical analysis and compared both uniformly and irregularly sampled model outputs to paleobiology series.

The six series (T, E_+, D, E_-, O, E) had fluctuation statistics that varied realistically with time scales Δt (lags) over the observed range (≈3 Myrs to ≈ 400 Myrs). In addition, the 15 pairwise fluctuation correlations (of the six variables) as functions of Δt were also very close to observations even though only two correlations were specified in the model ($TE_+$and TD). The ability to simulate the effects of irregular temporal sampling was important since model – data agreement was much better with realistic (irregular) sampling than with uniform sampling. Although the model could easily be made more complex, this may not be warranted until much higher resolution series become available.