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Emergent theories and predictive models in physics, biology, and beyond

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The success of science is due in large part to the hierarchical nature of physical theories. These effective theories model natural phenomena as if the physics at macroscopic length scales were almost independent of the underlying, shorter-length-scale details. Using information theory, the emergence of effective theories for long-scale observations can be traced to a systematic compression of the underlying parameter space when the observations are coarsened. This compression is quantified by the Fisher Information Matrix and is observed in other diverse areas of science for which effective theories have historically been difficult to find. Interpreting the underlying model as a manifold of predictions in data space, I show how effective models can be systematically derived from microscopic first principles for a variety of complex systems in physics, biology, and other fields.