Code

We provide a notebook to reproduce some of the core diagrams in this article here. (It isn't comprehensive, since we needed to rewrite code for our experiments to run outside our codebase.) We provide a separate notebook for the theoretical phase change diagrams.

Note that the reproductions by other researchers mentioned in comments above were not based on this code, but are instead fully independent replications with clean code from the description in an early draft of this article.

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Jeff Wu, Daniel Mossing, Tom McGrath, and Kshitij Sachan did independent replications of many of our experiments, greatly increasing our confidence in our results. Kshitij Sachan's and Tom McGrath's additional investigations and insightful questions both pushed us to clarify our understanding of the superposition phase change (both as reflected in this paper, and in further understanding which we learned from them not captured here). Buck Shlegeris, Adam Scherlis, and Adam Jermyn shared valuable insights into the mathematical nature of the toy problem and related work. Adam Jermyn also coined the term "virtual neurons."

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Author Contributions

Basic Results - The basic toy model results demonstrating the existence of superposition were done by Nelson Elhage and Chris Olah. Chris suggested the toy model and Nelson ran the experiments.

Phase Change - Chris Olah ran the empirical phase change experiments, with help from Nelson Elhage. Martin Wattenberg introduced the theoretical model where exact losses for specific weight configurations can be computed.

Geometry - The uniform superposition geometry results were discovered by Nelson Elhage and Nicholas Schiefer, with help from Chris Olah. Nelson discovered the original $m/||W||_F^2$ mysterious "stickiness". Chris introduced the definition of feature dimensionality. Nicholas and Nelson then investigated the polytopes that formed. As for non-uniform superposition, Martin Wattenberg performed the initial investigations of the resulting geometry, focusing on the behavior of correlated features. Chris extended this with an investigation of the role of relative feature importance and sparsity.

Learning Dynamics - Nelson Elhage discovered the "energy level jump" phenomenon, in collaboration with Nicholas Schiefer and Chris Olah. Martin Wattenberg discovered the "geometric transformations" phenomenon.

Adversarial Examples - Chris Olah and Catherine Olsson found evidence of a connection between superposition and adversarial examples.

Superposition with a Privileged Basis / Doing Computation - Chris Olah did the basic investigation of superposition in a privileged basis. Nelson Elhage, with help from Chris, investigated the "absolute value" model which provided a more principled demonstration of superposition and showed that computation could be done while in superposition. Nelson discovered the "asymmetric superposition" motif.

Theory - The theoretical picture articulated over the course of this paper (especially in the "mathematical understanding" section) was developed in conversations between all authors, but especially Chris Olah, Jared Kaplan, Martin Wattenberg, Nelson Elhage, Tristan Hume, Tom Henighan, Catherine Olsson, Nicholas Schiefer, Dawn Drain, Shauna Kravec, Roger Grosse, Robert Lasenby, and Sam McCandlish. Jared introduced the strategy of rewriting the loss by grouping terms with the number of active features. Both Jared and Martin independently noticed the value of investigating the $n = 2; m = 1$ case as the simplest case to understand. Nicholas and Dawn clarified our understanding of the connection to compressed sensing.