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Title: An approximate line attractor in the hypothalamus that encodes an aggressive internal state

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Abstract: In vertebrates, the hypothalamus plays a key role in regulating innate survival behaviors. The prevailing view of the hypothalamus is that its circuits are developmentally hardwired, or 'labelled line' pathways, incorporating populations of behavior-specific neurons with characteristic transcriptional and connectomic profiles. This model seems to fit regions such as the medial preoptic area (MPOA, whose activation causes reproductive behaviors), which contains multiple behavior-specific neuronal populations with distinct transcriptional profiles. However other structures, such as the ventrolateral subdivision of the ventromedial hypothalamus (VMHvl, whose activation causes scalable aggression), exhibit only weak tuning for experimenter-identified behaviors like attack and mating.

We adopt an unsupervised dynamical systems framework to characterize neural activity of ESR1 neurons in the MPOA and VMHvl of interacting mice in a user-unbiased manner divorced from any behavior annotation. Our results suggest that activity in the VMHvl represents state rather than behavior: the low-dimensional dynamics of our fit model reveal one dimension with slow-ramping dynamics and persistent activity that correlates with escalating aggressive and is implemented as an approximate line attractor. Intriguingly, the time constant of this dimension is a strong predictor of time animals spend fighting. These line-attractor representations suggest a function for the VMHvl to encode the intensity of behavior-relevant motivational states and are compatible with results of earlier optogenetic stimulation experiments. Importantly, line-attractor dynamics are not an arbitrary result of our fitting process, as models fit to MPOA activity revealed states that precisely correlate with the animals' behavior. The low-dimensional dynamics of the MPOA contained behaviorally tuned factors that display rotational dynamics during mating episodes, suggesting an encoding of actions rather than state. Thus, our analysis of dynamics reveals two distinct organizations of computation in the hypothalamus, one based on action encoding populations in MPOA and another population encoding motivational state in VMHvl.