Title: ...

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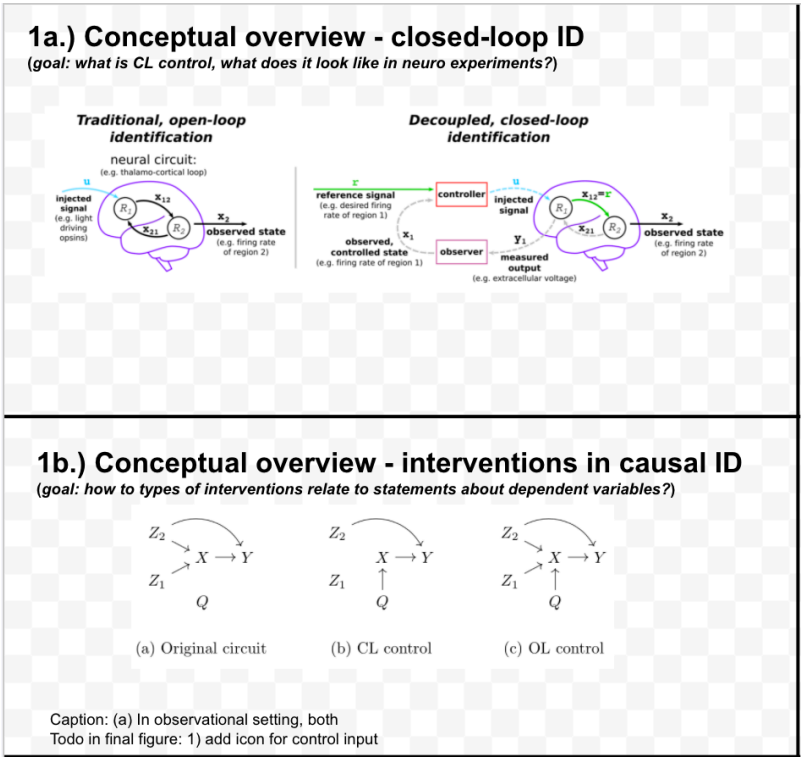
Abstract

The necessity of intervention in inferring cause has long been understood in neuroscience. Recent work has highlighted the limitations of passive observation and single-site lesion studies in accurately recovering causal circuit structure. The advent of optogenetics has facilitated increasingly precise forms of intervention including closed-loop control which may help eliminate confounding influences. However, it is not yet clear how best to apply closed-loop control to leverage this increased inferential power. In this paper, we use tools from causal inference, control theory, and neuroscience to show when and how closed-loop interventions can more effectively reveal causal relationships. We also examine the performance of standard network inference procedures in simulated spiking networks under passive, open-loop and closed-loop conditions. We demonstrate a unique capacity of feedback control to distinguish competing circuit hypotheses by disrupting connections which would otherwise result in equivalent patterns of correlation. Our results build toward a practical framework to improve design of neuroscience experiments to answer causal questions about neural circuits.

Introduction

Estimating causal interactions in the brain



https://github.com/awillats/clinc/blob/main/figures/core_figure_sketches/figure1_sketch.png

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Interventions in neuroscience & causal inference

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@ import "section_content/background_intervention_causal_inf.md"

Representations & reachability

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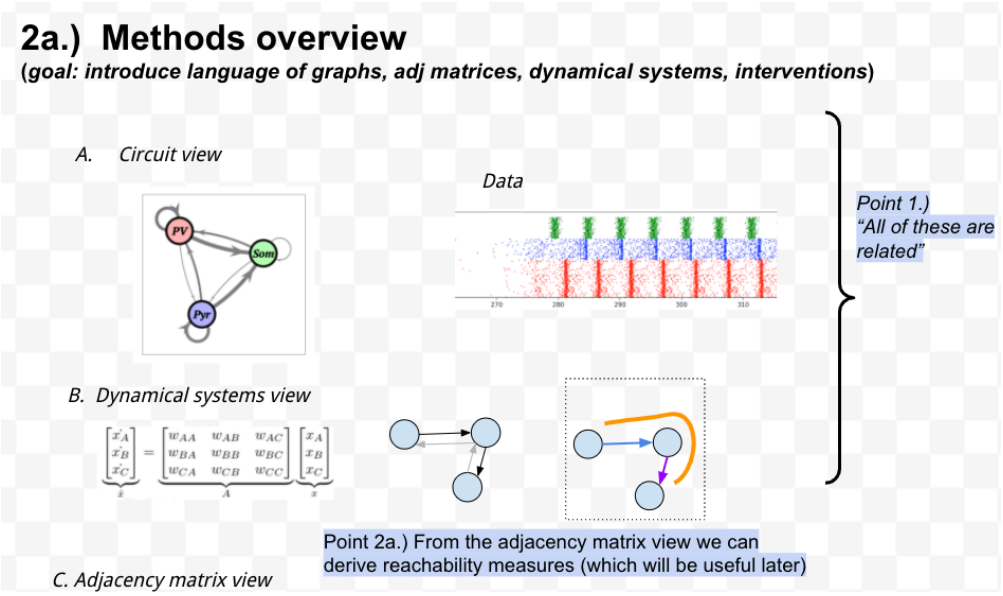

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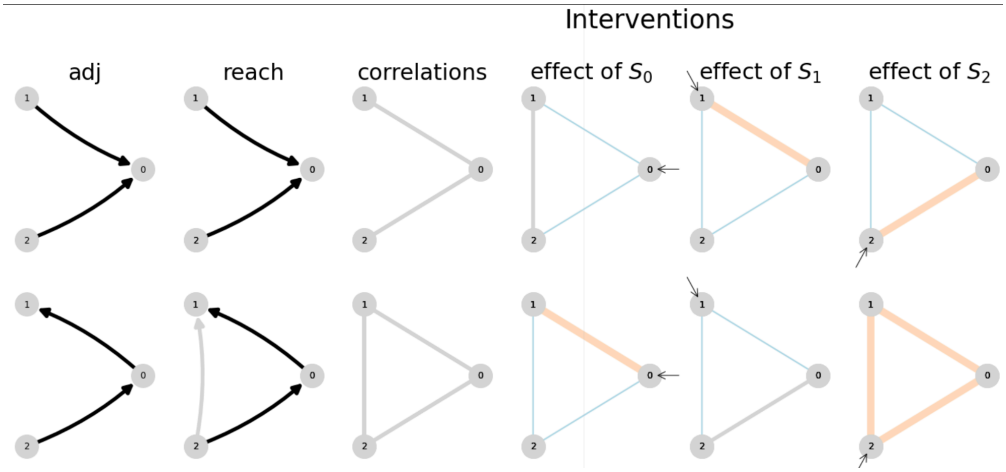


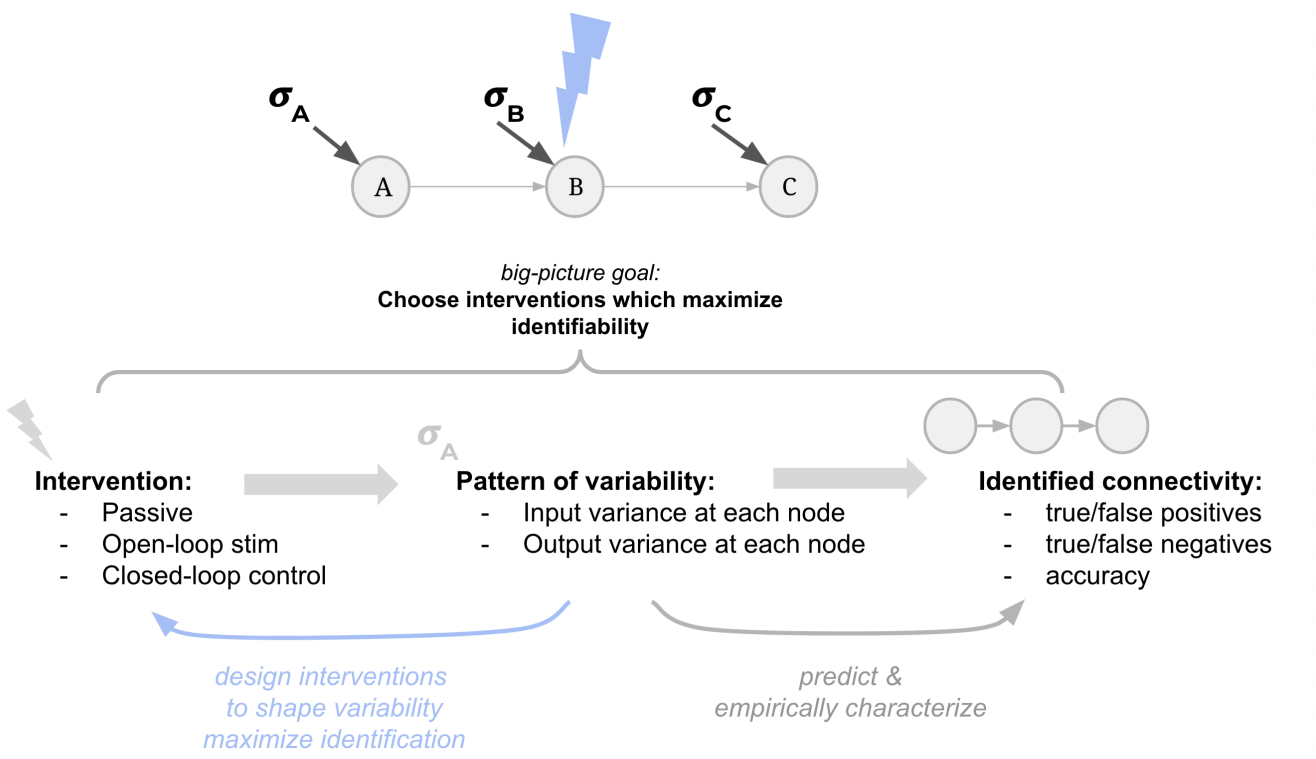
https://github.com/awillats/clinc/blob/main/figures/misc_figure_sketches/two_circuit_case_study_mockup.png

Figure DEMO: Applying CLINC to distinguish a pair of circuits

Theory / Prediction

Computing reachability (theory)

Predicting correlation structure (theory)



https://github.com/awillats/clinc/blob/main/figures/misc_figure_sketches/intervention_identifiability_concept.png

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Simulation

Network simulations (simulation)

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Implementing interventions (simulation)

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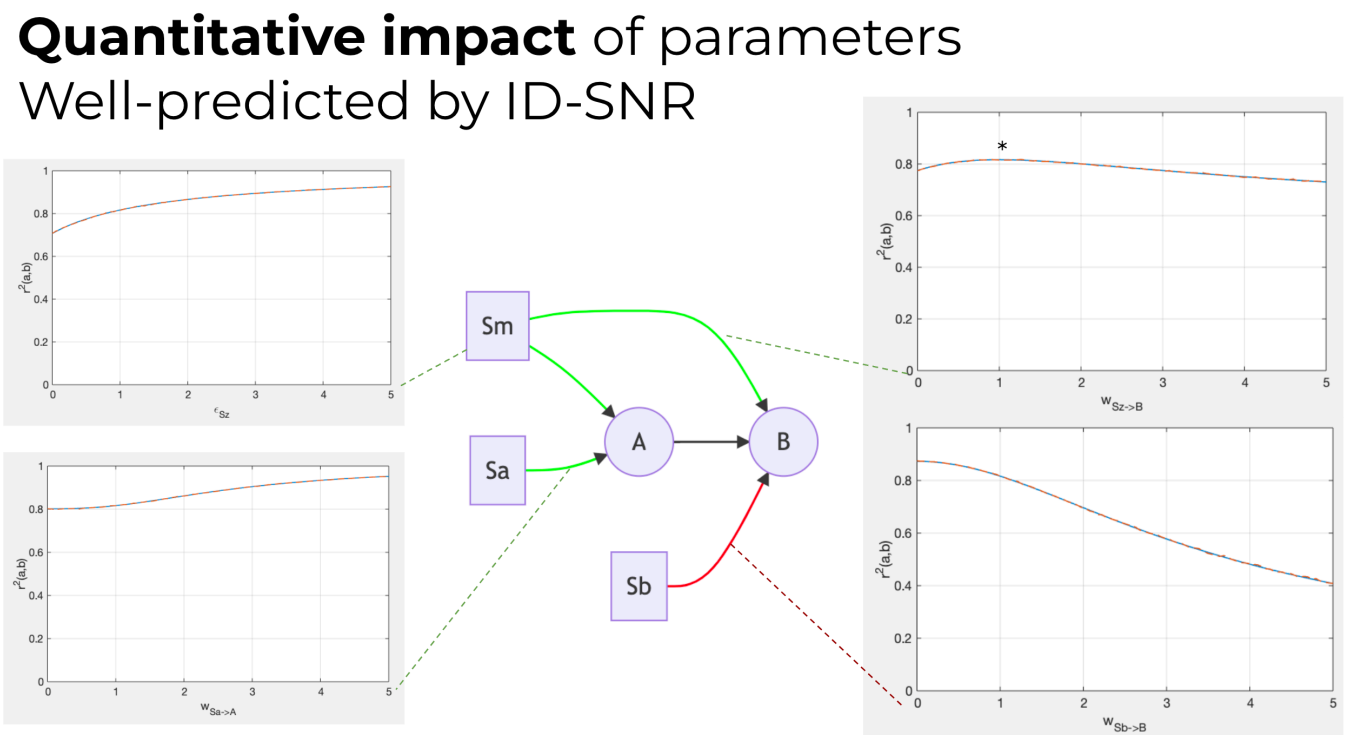
Extracting circuit estimates (empirical)

Information-theoretic measures of hypothesis ambiguity

Results

Impact of node, network parameters on estimation performance



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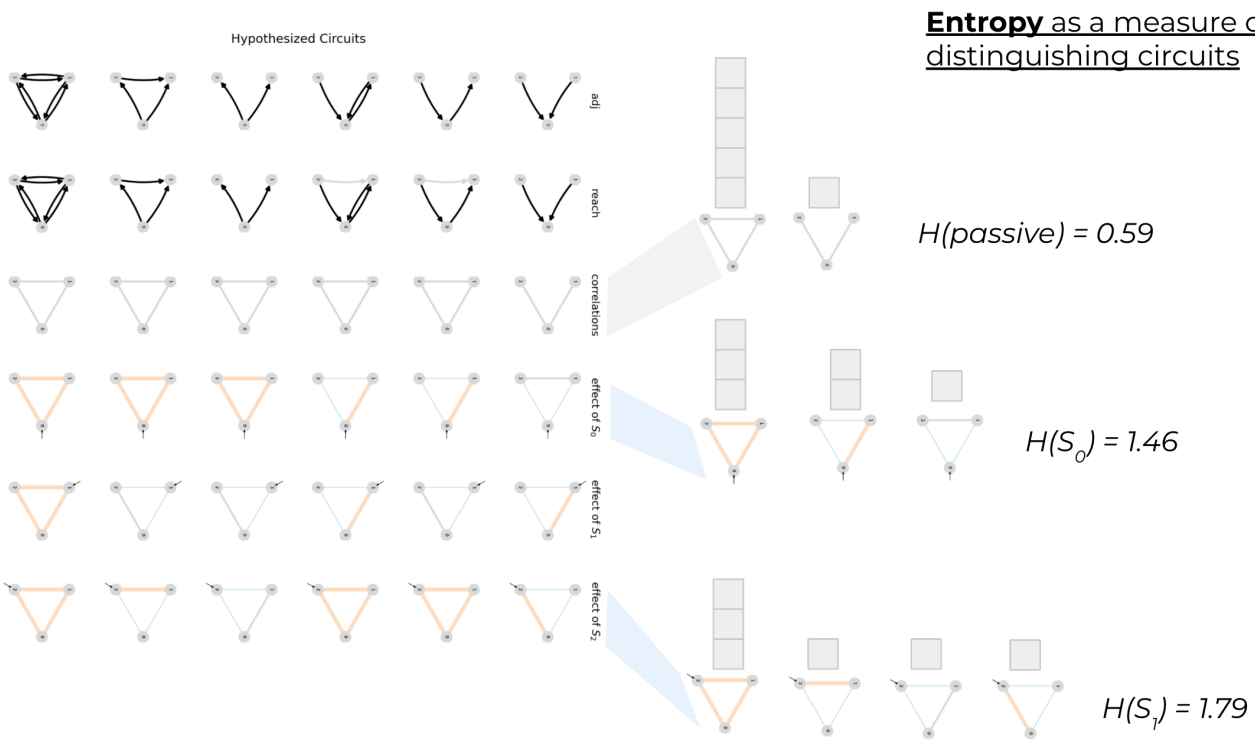
Impact of intervention & circuit structure



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Discussion

References

Supplement