COMPUTATION-ACTIVATION NETWORKS - UNIFYING PROBABILISTIC AND LOGICAL REASONING

RESEARCH NOTES IN THE ENEXA PROJECT

August 23, 2025

ABSTRACT

We introduce a novel architecture for tensor networks, which is adapted to represent propositional formulas and exponential distributions.

1 Motivation

Models which combine

- hard features: Always satisfied and necessary for non-vanishing probability.
- soft features: Typically satisfied

2 Notation and Basic Concepts

from *Chapter cha:notation*:

- Tensor Notation: Directed tensors, tensor networks, contractions (from *Chapter cha:notation*)
- Basis encodings

from *Chapter cha:probRepresentation*:

- Computation-Activation Networks as contractions of Basis encodings (computing a statistic) and activation tensors (shaping the distribution based on the computed statistic).

from *Chapter cha:basisCalculus*:

- Tensor Network decompositions for composed functions

3 Hard Activation: Propositional Formulas

from *Chapter cha:logicalRepresentation*:

- Propositional Semantics by Boolean Tensors
- Propositional Syntax leading to Tensor-Network Decompositions
- Contractions to decide entailment

4 Soft Activation: Exponential Families

from *Chapter cha:probRepresentation*:

- Sufficient statistics leading to tensor network decompositions ("the computation mechanism")
- Exponential families in case of elementary activation tensors
- Example of graphical models, reference to "the independence mechanism"
- Contractions to compute marginal probabilities

5 Hybrid Logic Networks

from *Chapter cha:networkRepresentation*:

- Unification of both frameworks by allowing for arbitrary elementary activation tensors
- Entailment decision by hard parts
- Optional: Mean parameter polytope, hard parameters by corresponding face measures
- Optional: Extension by CP activation tensors

from *Chapter cha:networkReasoning*:

- Alternating Moment Matching for maximum likelihood estimation
- Optional: Structure learning