Tensia

Actor-based tensor network simulation

Bartosz Błaszków[1], Mateusz Front[1], Katarzyna Rycerz[1], Piotr Gawron[2]

[1] AGH University of Science and Technology, Institute of Computer Science AGH, Department of Computer Science
[2] Institute of Theoretical and Applied Informatics, Polish Academy of Sciences

Table of contents

Tensia

- Tool supporting analysis and operations on tensor networks
- Written in Scala and C
- Utilizing Akka Actors for parallel computation

Motivation

- Research usefulness of new tchnologies
- Tensor Networks are a convenient form of expressing problems from quantum physics and chemistry
  - Simulation of continuous-time stochastic automata networks
  - Deep neural networks
  - Hyperspectral image analysis
  - Quantum circuit simulation

Tensor

Notice

There are several approaches to the definition of tensor. This is just one of them (a bit simplified)

- Generalization of vector
- Representation: N-dimensional array
- Contains *scalar components* denoted by indices
- Number of dimensions is it's *rank* (also called *degree* or *order*)

Contraction

Sum over all the possible values of the repeated indices of a set of tensors.

Example

$C_{abe} = \sum_{cd} A_{abcd} \cdot B_{cde}$

Computational complexity

$$countOfMultiplications = \frac{size(A) \cdot size(B)}{\prod contractedDims(A, B)}$$

Resulting size

$$size(C) = \frac{size(A) \cdot size(B)}{\prod contractedDims(A, B)^2}$$

Tensor Network

- A set of tensors where some of its indices are contracted
- Represented by diagrams
- Problem: reduce to a single tensor

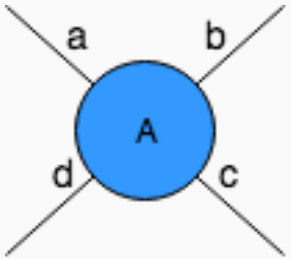


Figure 1: Tensor on Tensor Network diagram

Tensor Network

- A set of tensors where some of its indices are contracted
- Represented by diagrams
- Problem: reduce to a single tensor

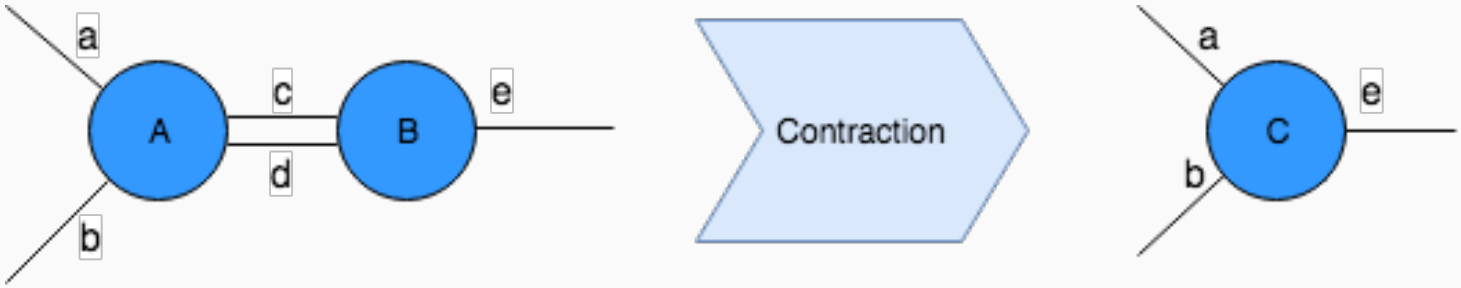


Figure 2: Contraction shown on Tensor Network diagram

Tensor Network

- A set of tensors where some of its indices are contracted
- Represented by diagrams
- Problem: reduce to a single tensor

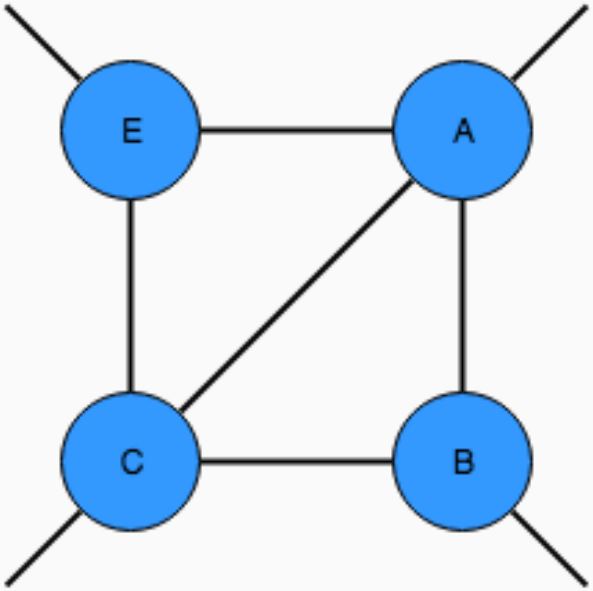


Figure 3: An example of Tensor Network

Simulation flow

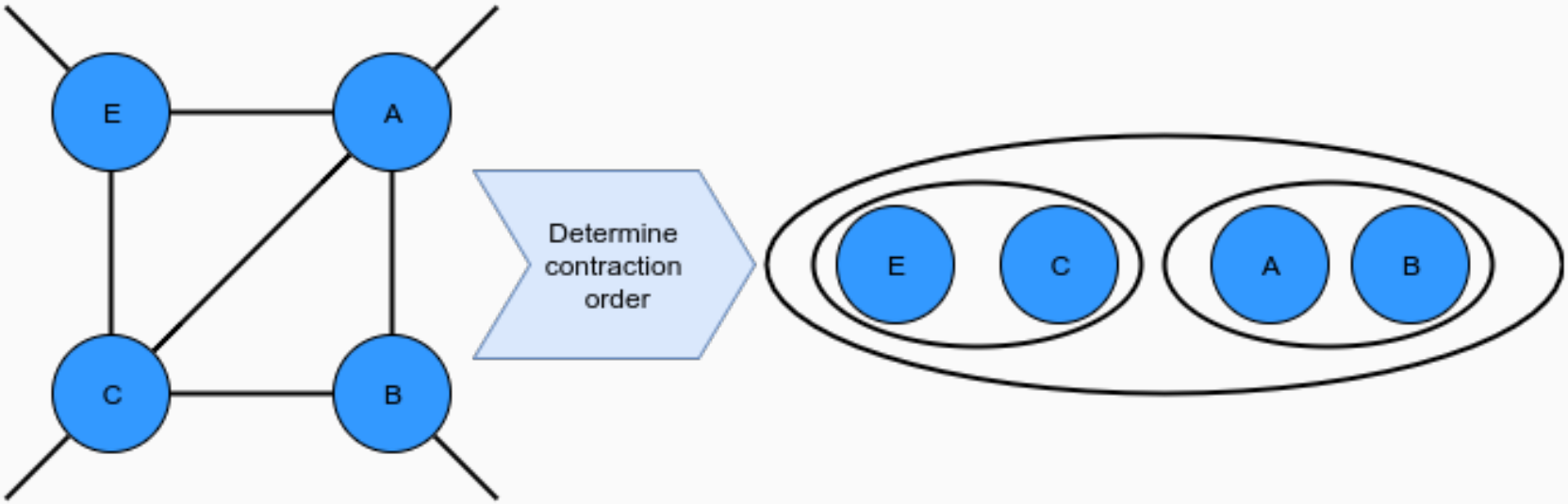


Figure 4: Simulation: choosing order of contraction

Simulation flow

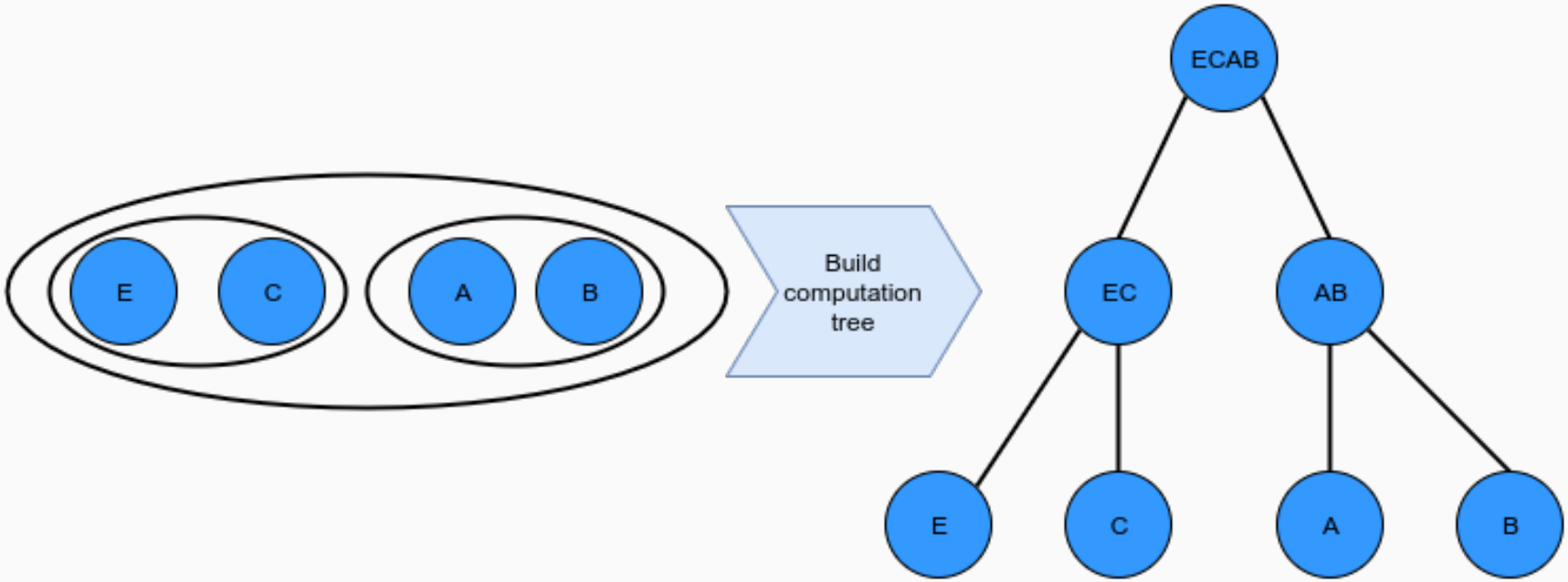


Figure 5: Simulation: constructing computation tree

Simulation flow

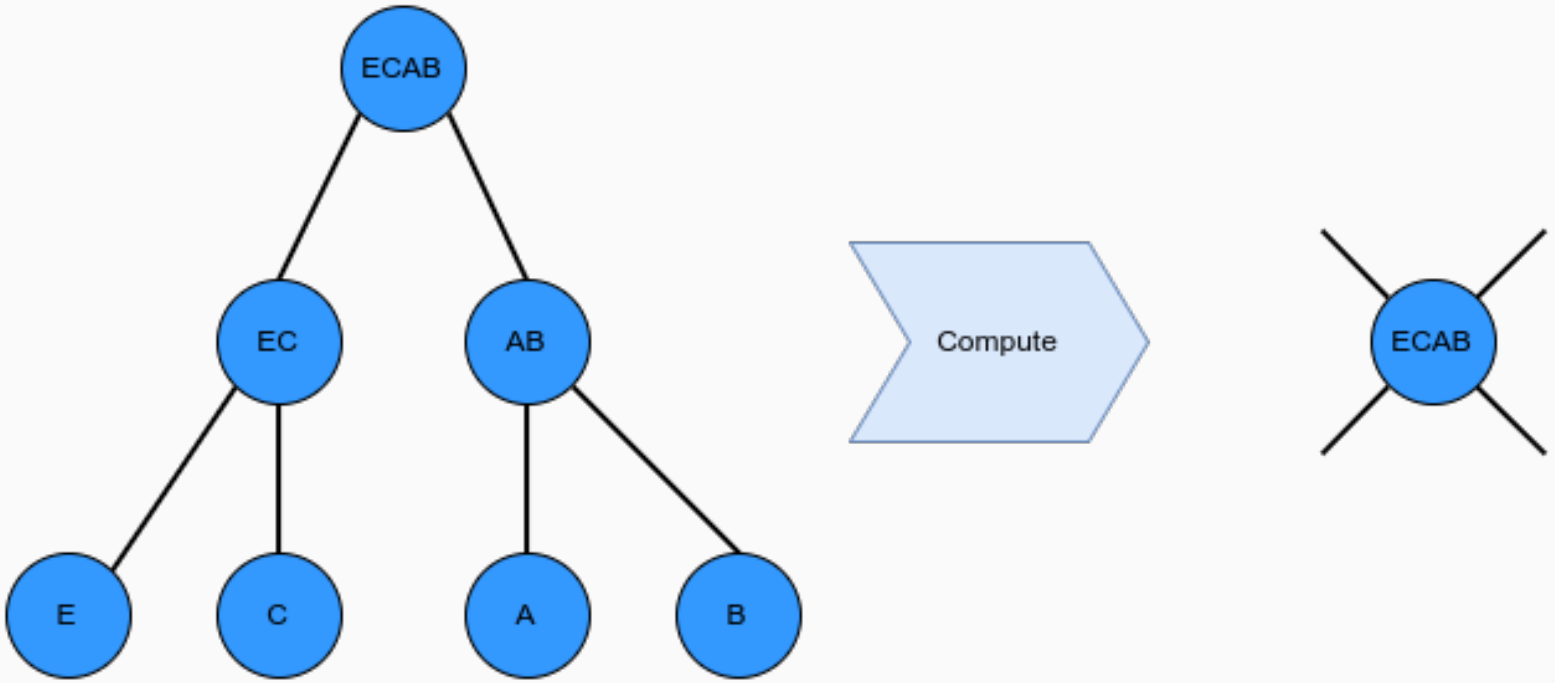


Figure 6: Simulation: reduction to the resulting tensor

Contraction order

Why it's important?

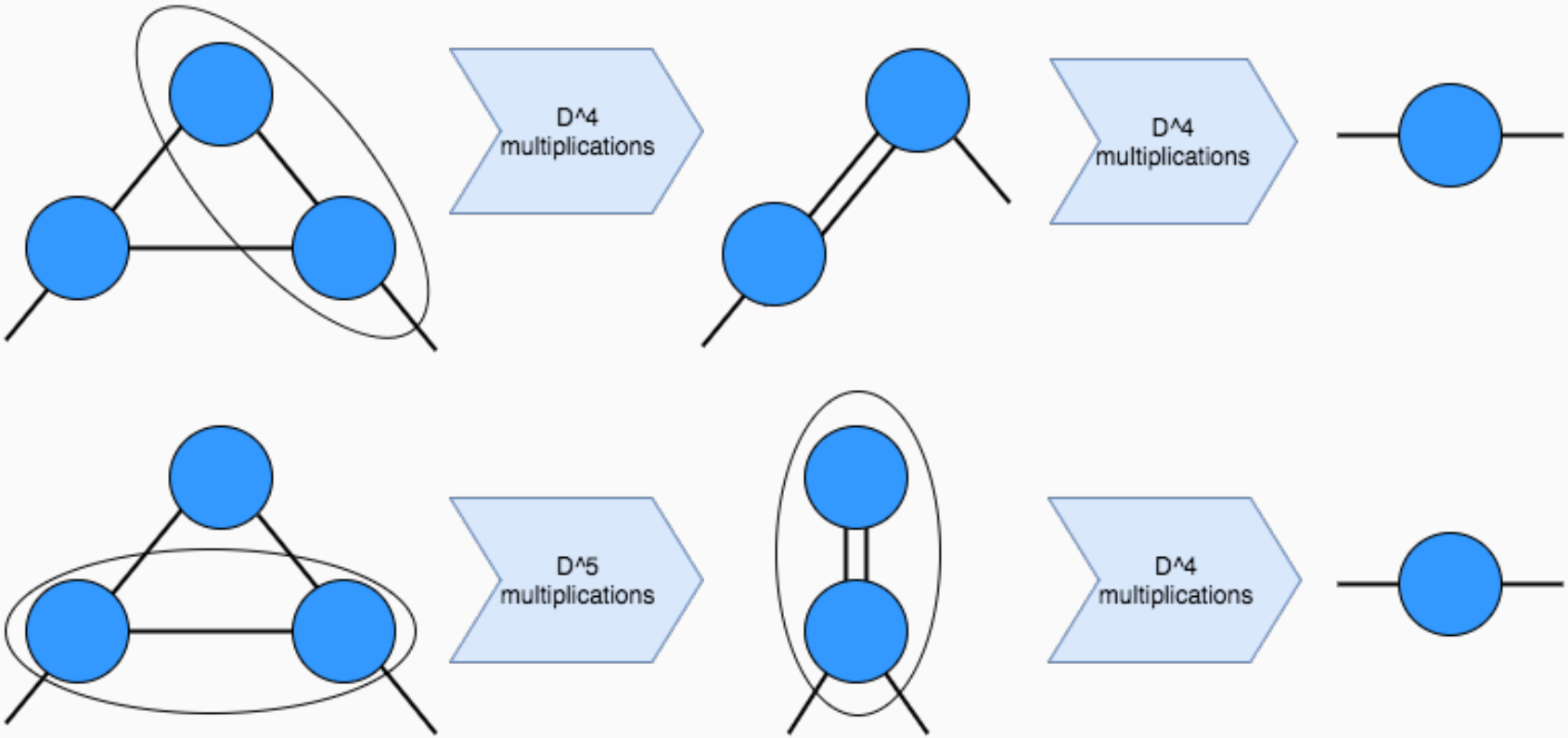


Figure 7: Different ways of contracting tensor network

Contraction order

- Lowest-cost contraction order problem is NP-hard :(
- Currently using brute-force $O(4^n)$ algorithm
- Working on speeding it up

Actor model

- Model of concurrent computation
- Everything is an actor
- Asynchronous message passing

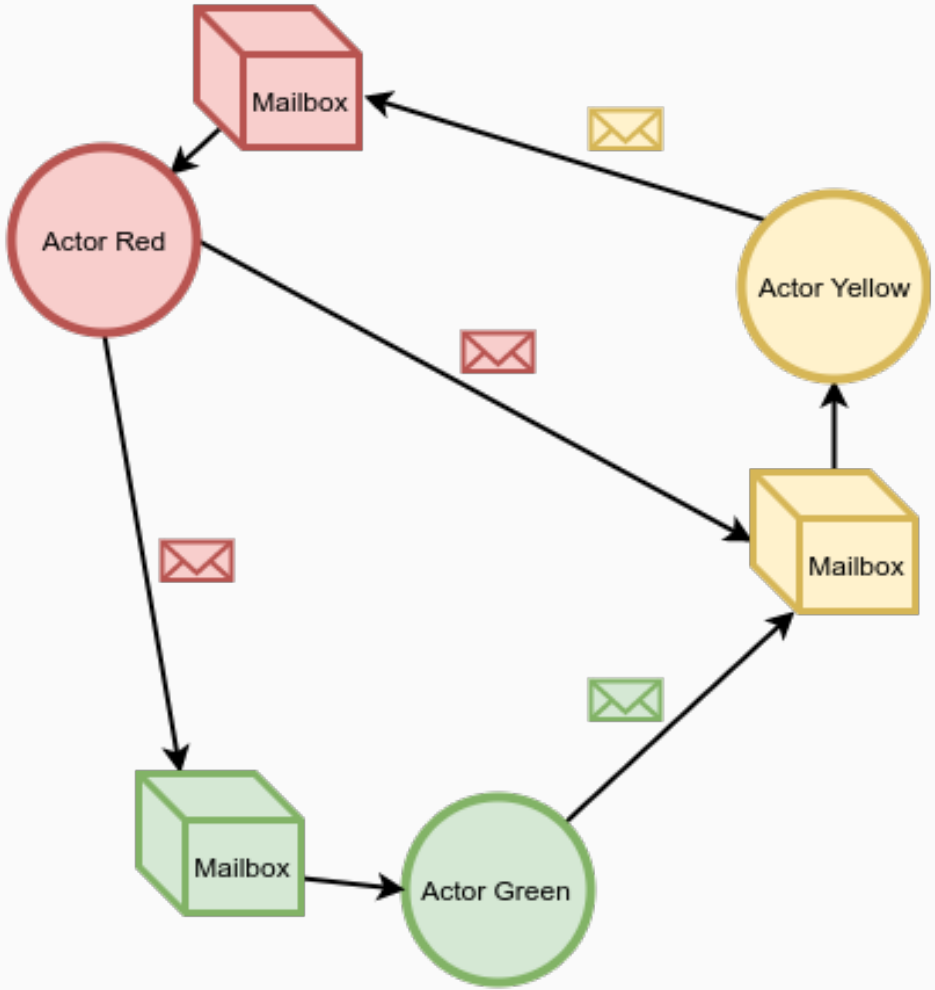
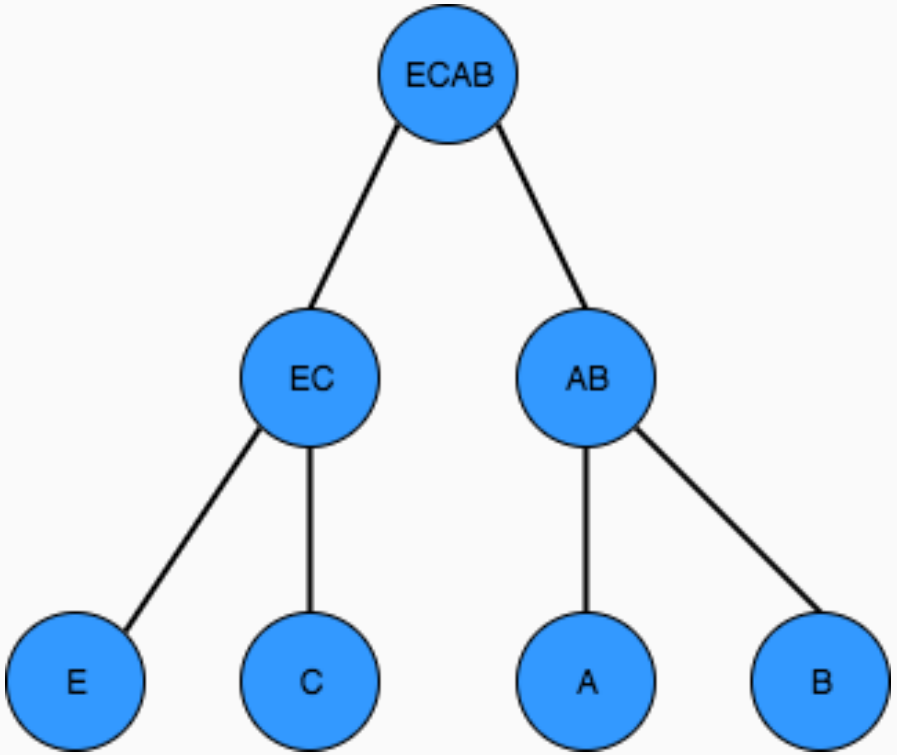


Figure 8: Actor model

Parallel computation

- Use of Akka actors
- Supervision tree



Contraction engine

- Use of ND4J library
- Reshaping tensors to matrices
- Performing BLAS matrix multiplication
- Reshaping result back to proper dimensions

Example

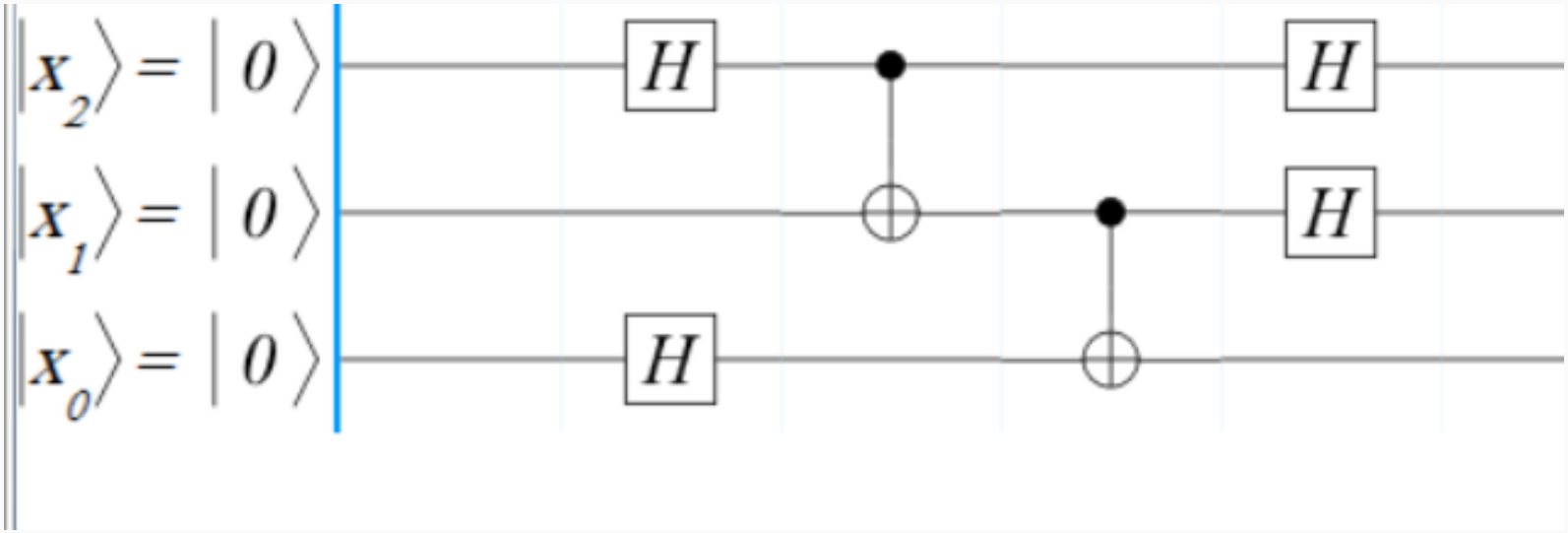


Figure 9: Simple quantum circuit

$$H = \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix}$$

Figure 10: Hadamard gate matrix

$$C_{10} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Figure 11: Cnot gate matrix

Example

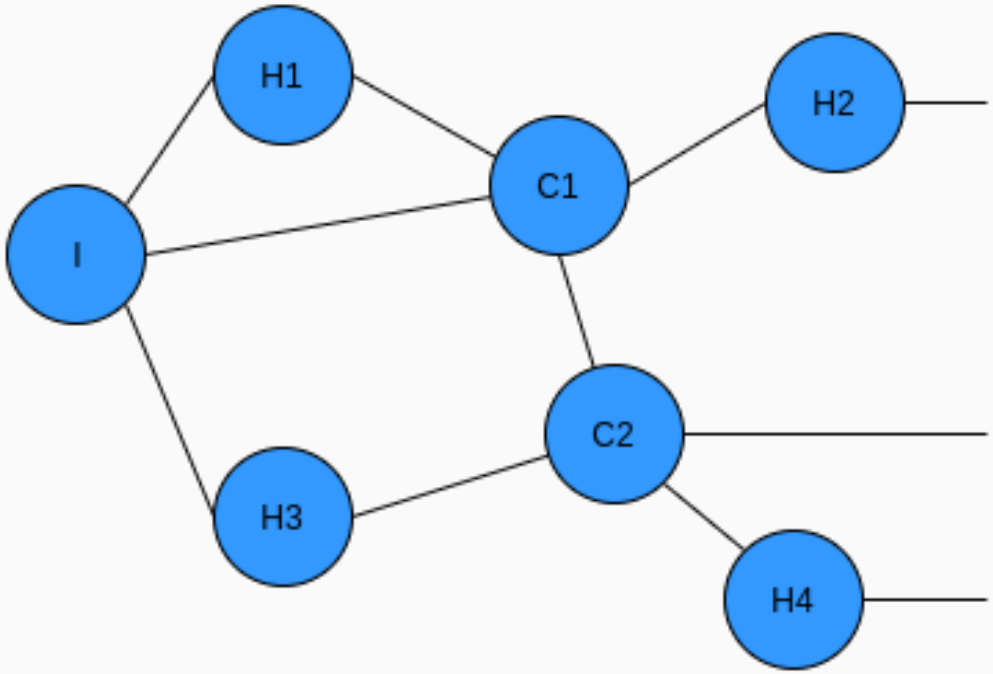


Figure 12: Circuit as a tensor network

Example results

$$\begin{vmatrix} 0.5 \\ 0 \\ 0.5 \\ 0 \\ 0 \\ 0.5 \\ 0 \\ -0.5 \end{vmatrix}$$

Questions?

Thank you for your attention

`github.com/tensia/tensia`

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