Generative Modeling

From Boltzmann Machines to Born Machines

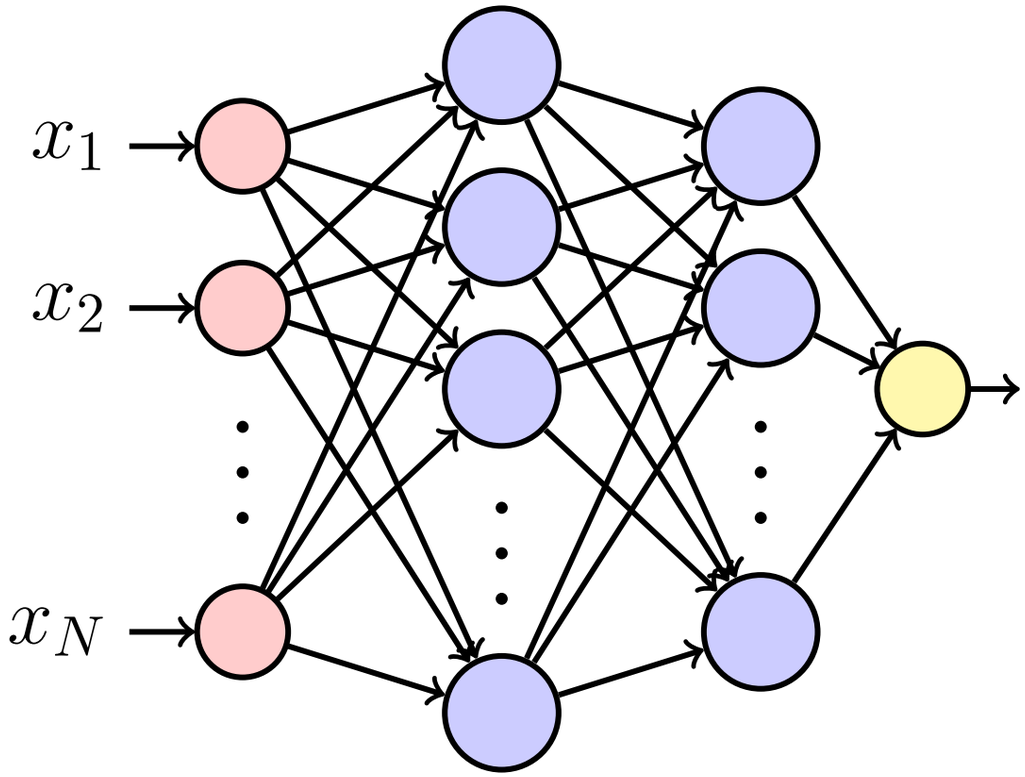
Lei Wang (王磊)
Institute of Physics, CAS
https://wangleiphy.github.io

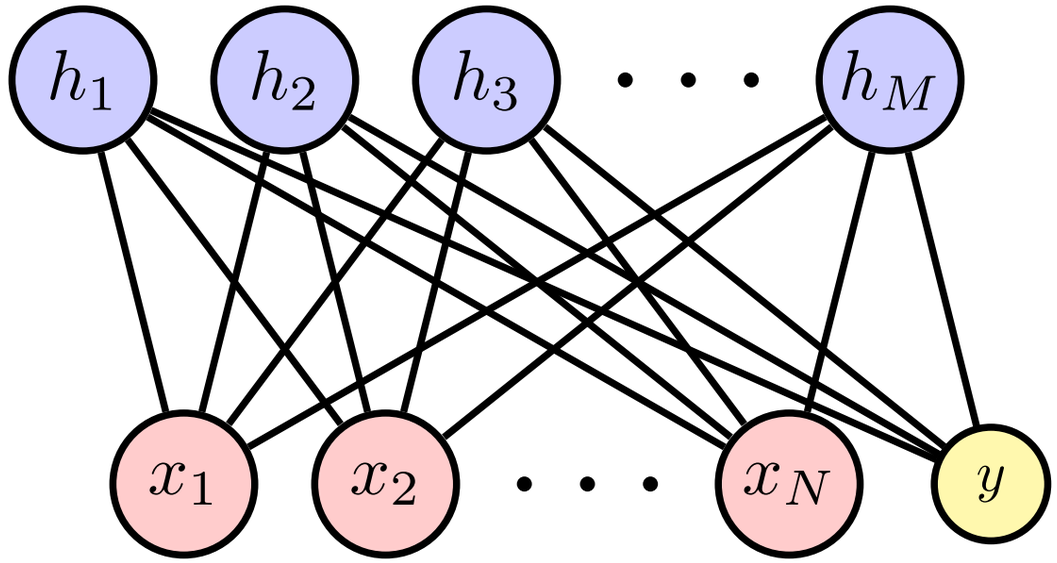
Discriminative vs Generative Learning

read

write

Discriminative vs Generative Learning



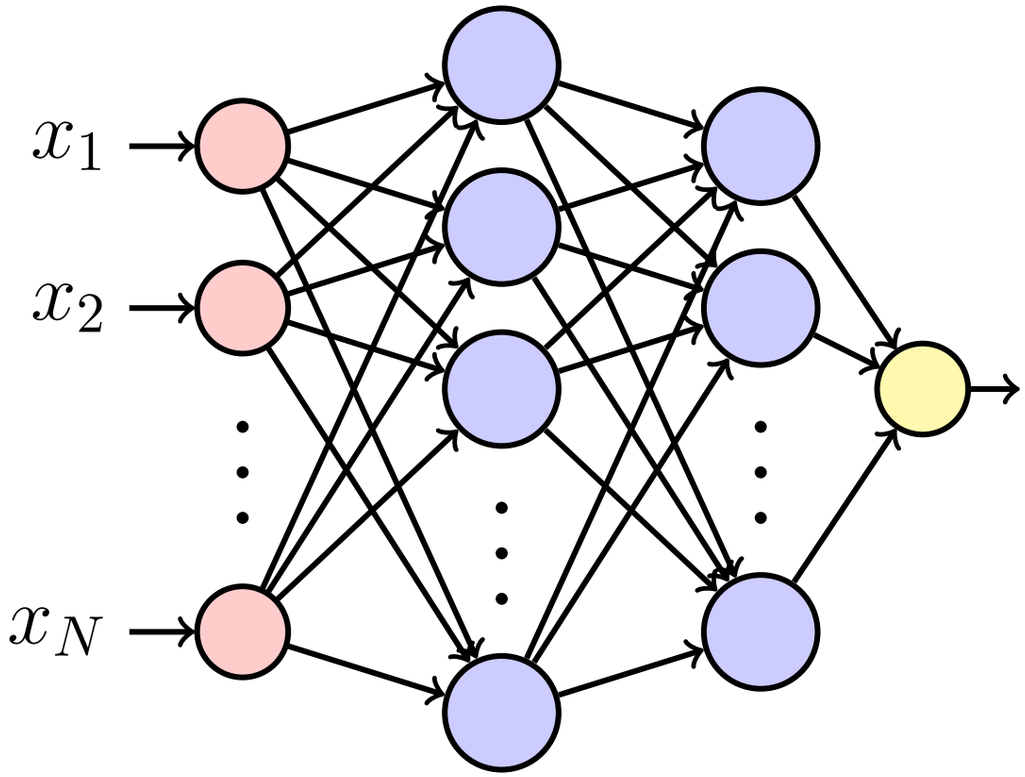


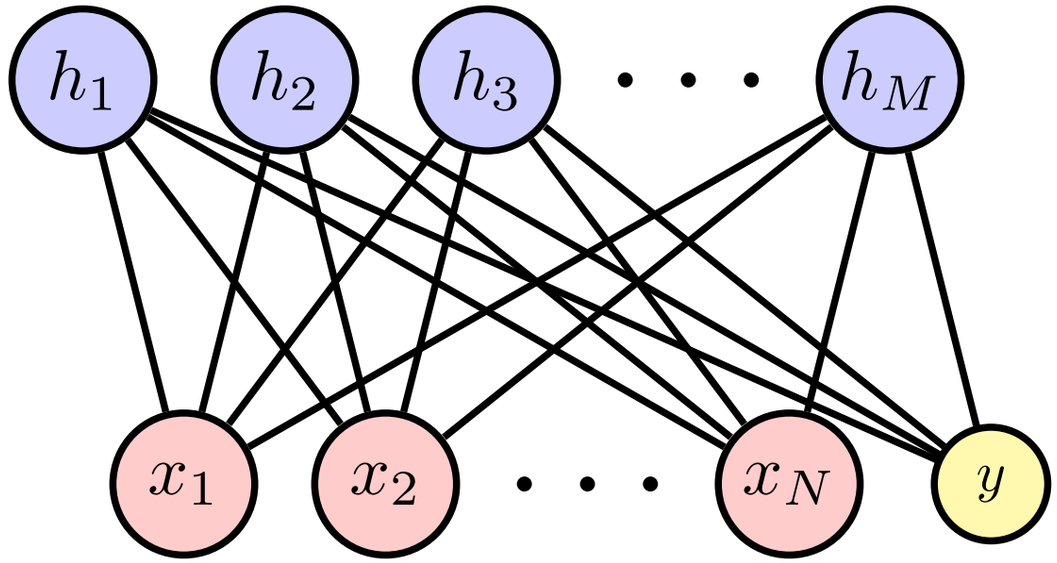
$$y = f(\mathbf{x})$$

or $p(y|\mathbf{x})$

$$p(\mathbf{x}, y)$$

Discriminative vs Generative Learning



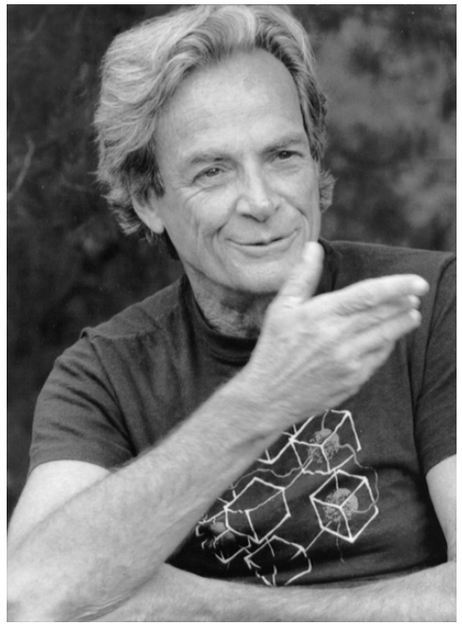


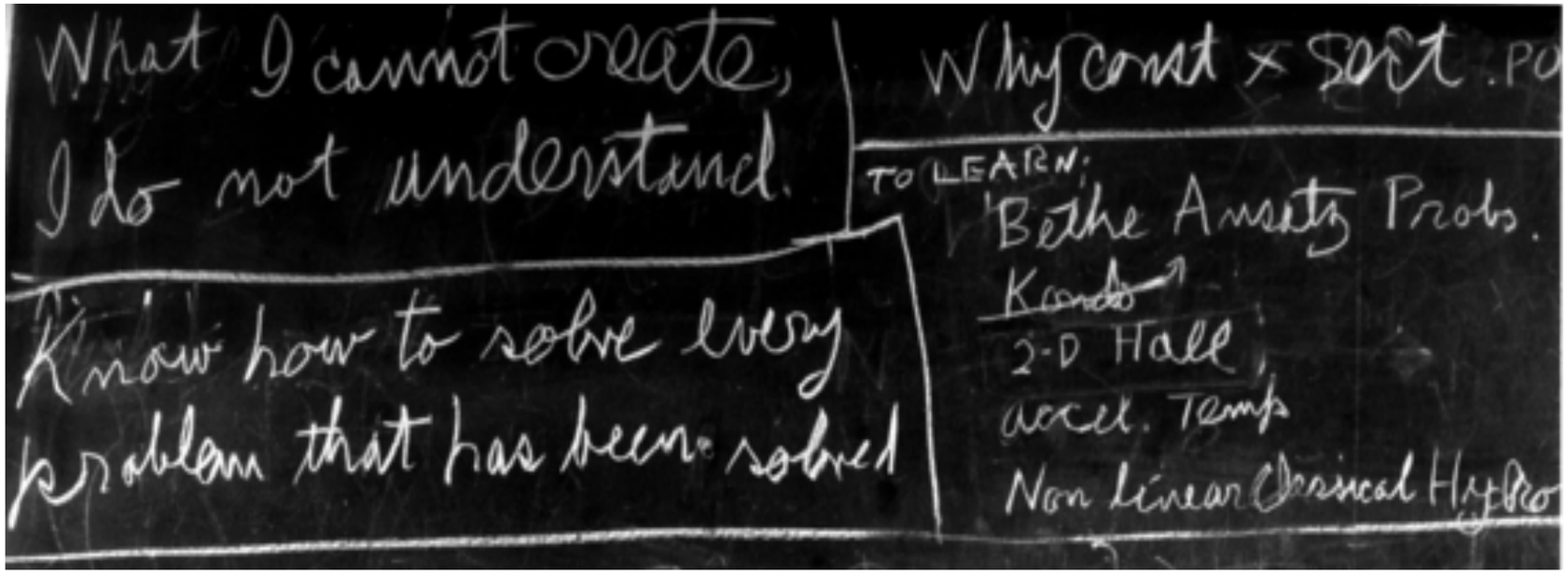
$$y = f(\mathbf{x})$$

or $p(y|\mathbf{x})$

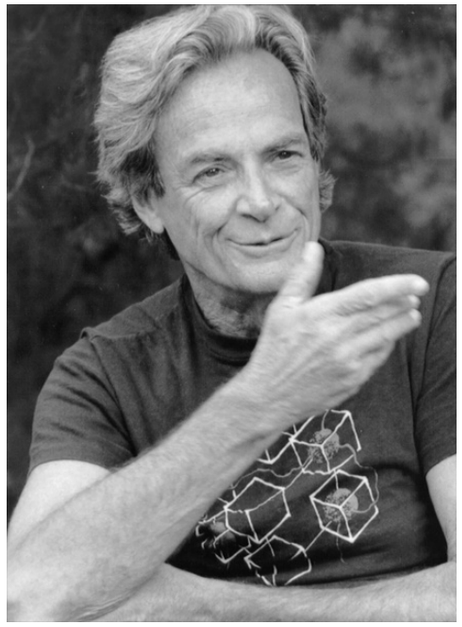
$$p(y|\mathbf{x}) = \frac{p(\mathbf{x}, y)}{p(\mathbf{x})}$$

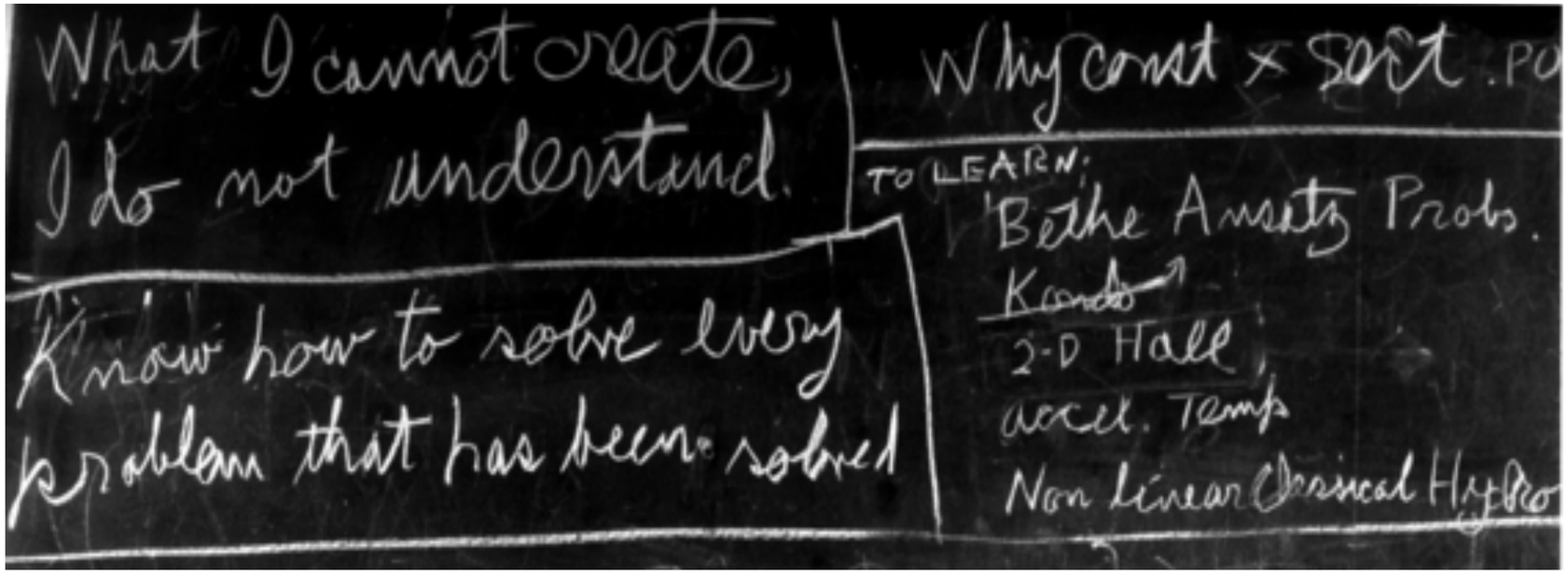
Discriminative vs Generative Learning





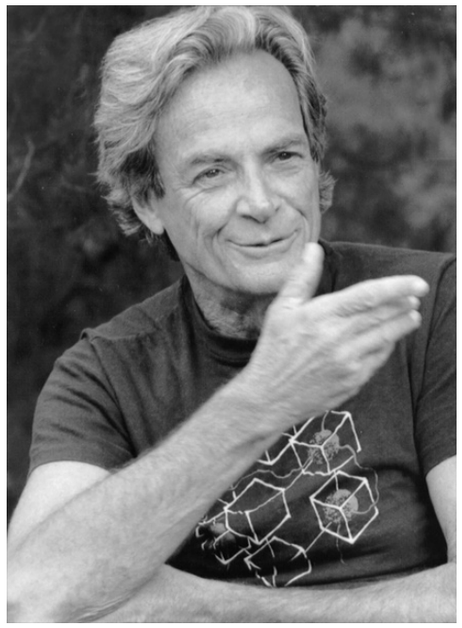
Discriminative vs Generative Learning

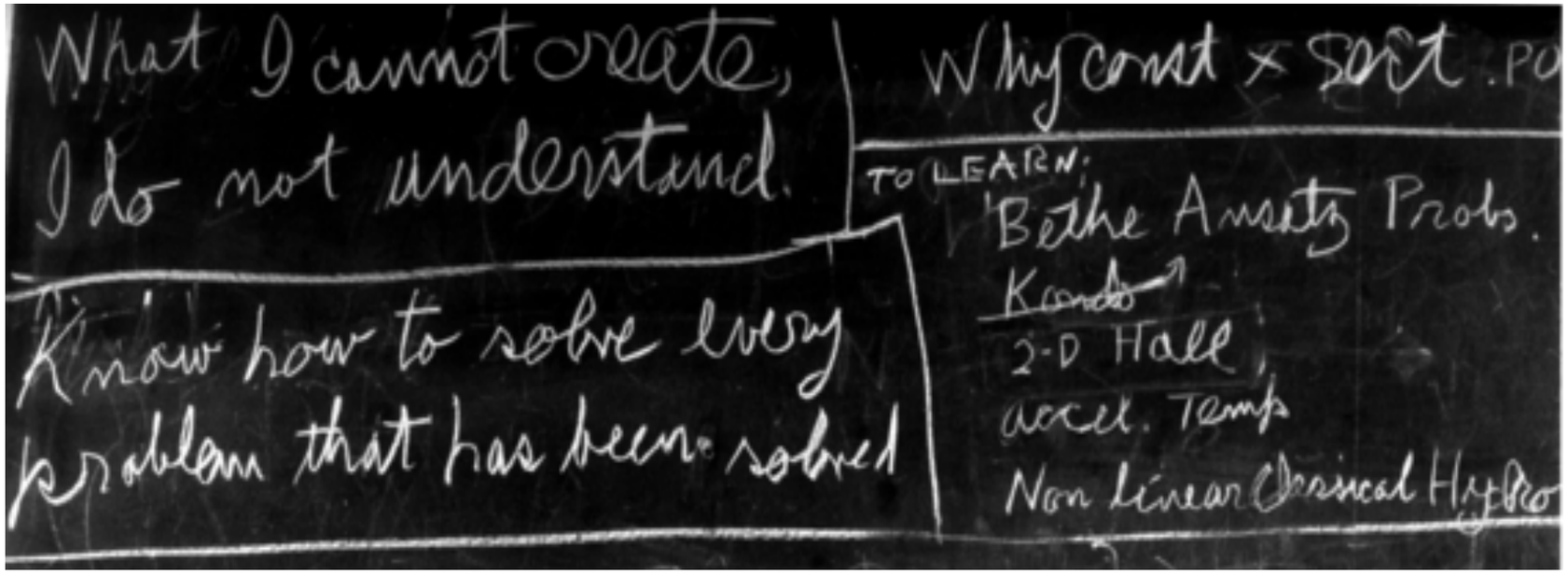




"What I can not create, I do not understand"

Discriminative vs Generative Learning





ELSEVIER

Progress in Brain Research

Volume 165, 2007, Pages 535–547

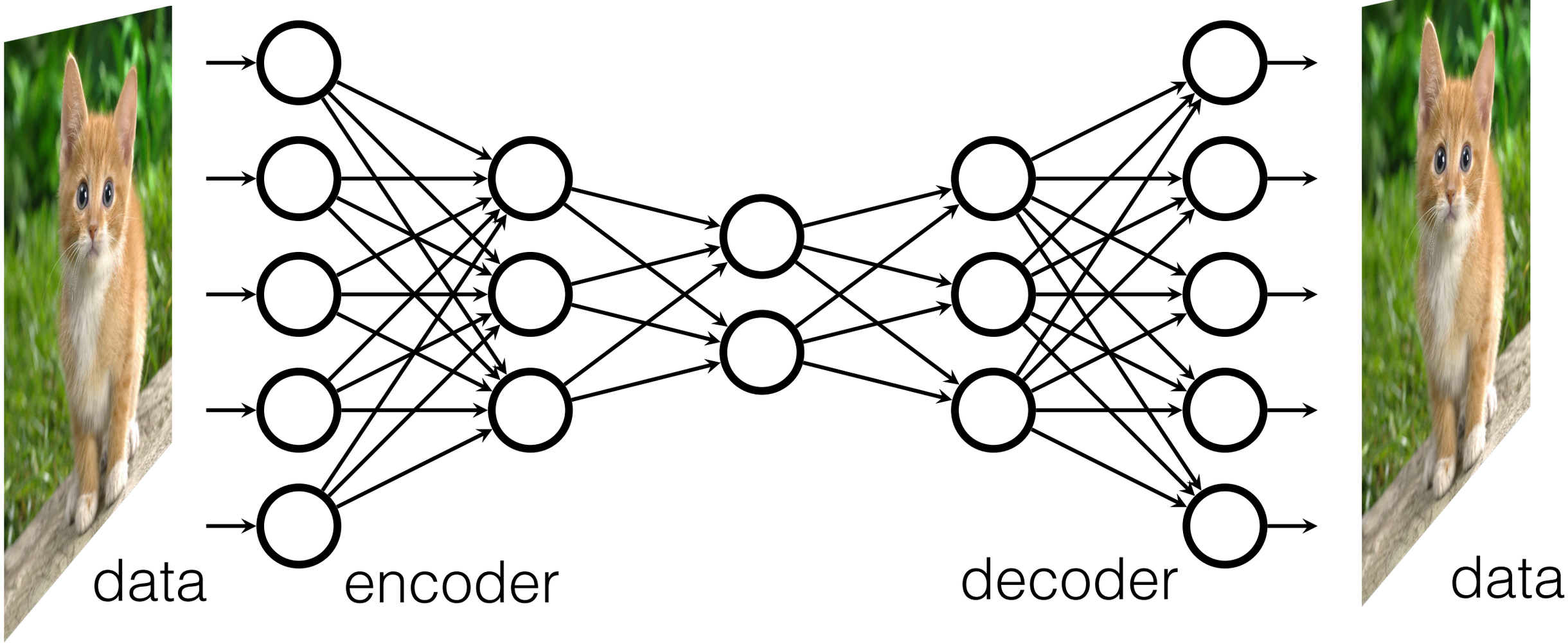
Computational Neuroscience: Theoretical Insights into Brain Function

To recognize shapes, first learn to generate images

Geoffrey E. Hinton

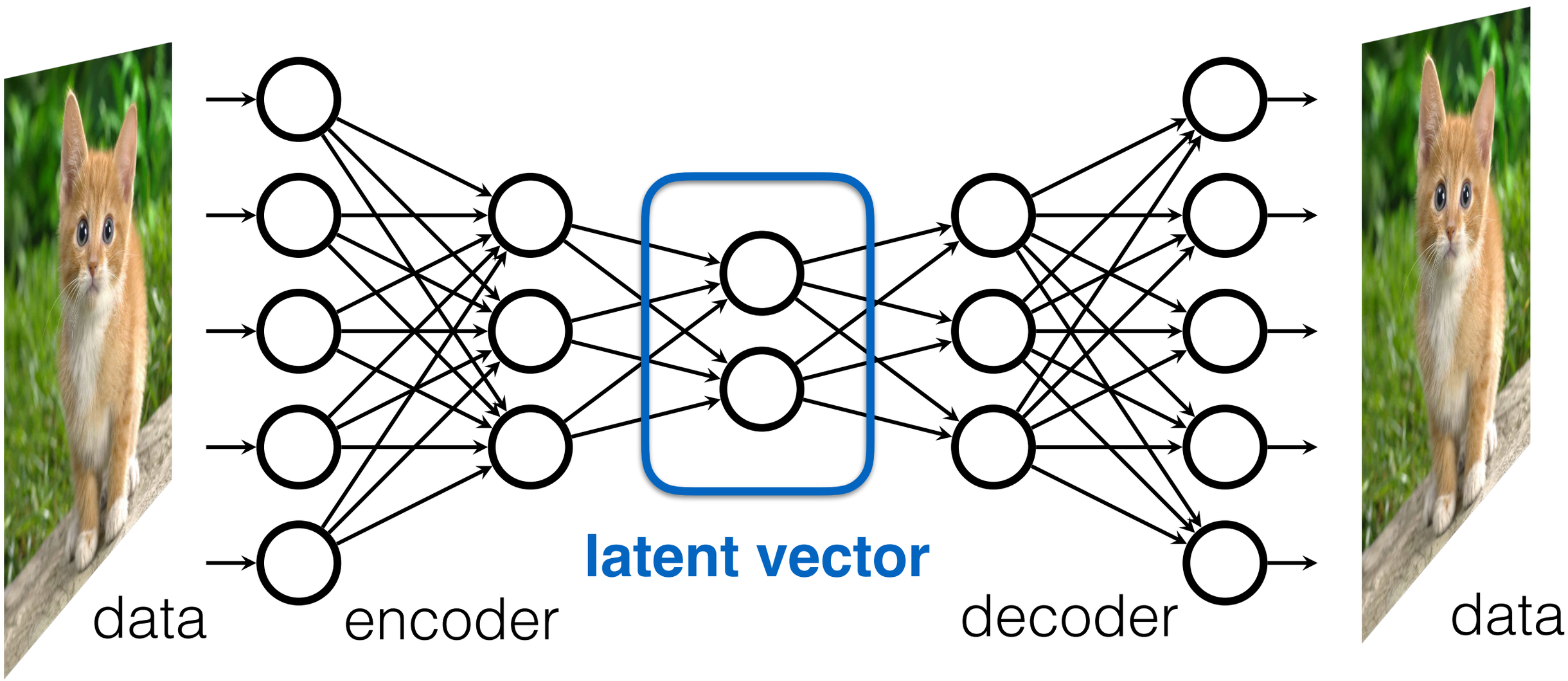
Department of Computer Science, University of Toronto, 10 Kings College Road, Toronto, M5S 3G4 Canada

Generative Modeling



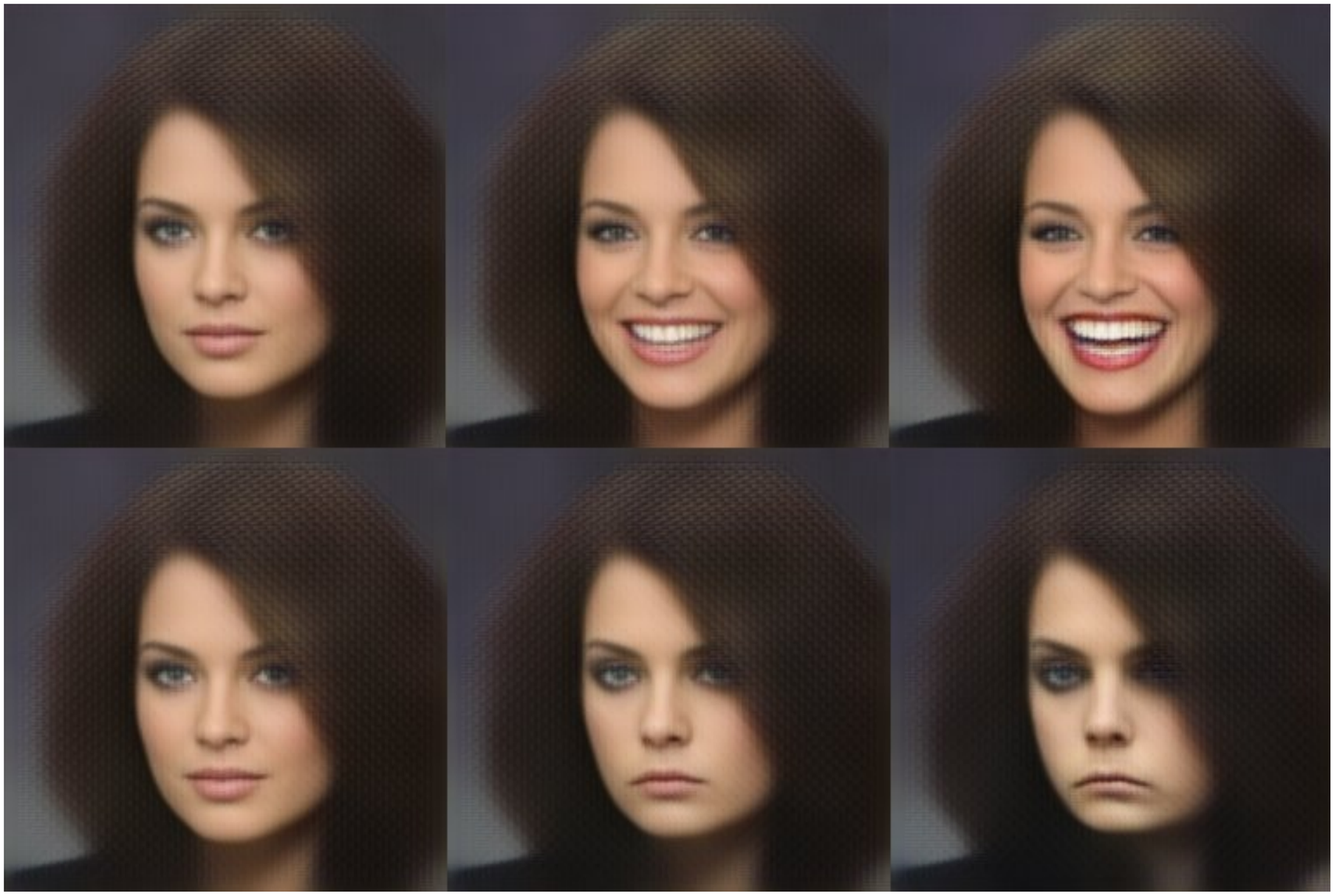
“Auto-Encoding Variational Bayes", Kingma and Welling,1312.6114

Generative Modeling



“Auto-Encoding Variational Bayes", Kingma and Welling,1312.6114

Latent space interpolation

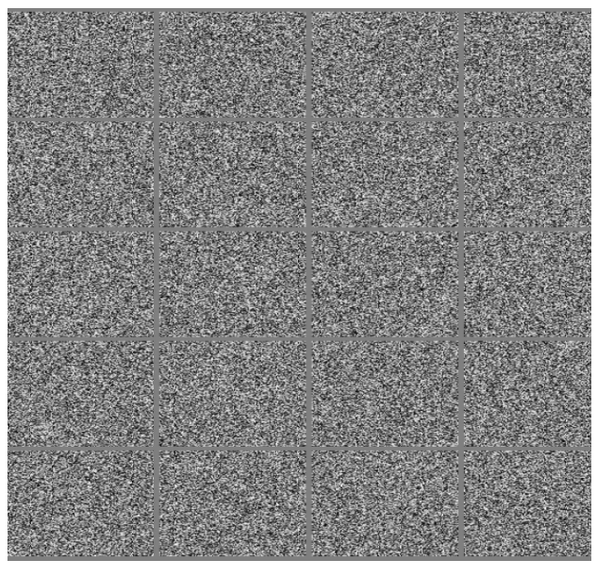


White, 1609.04468

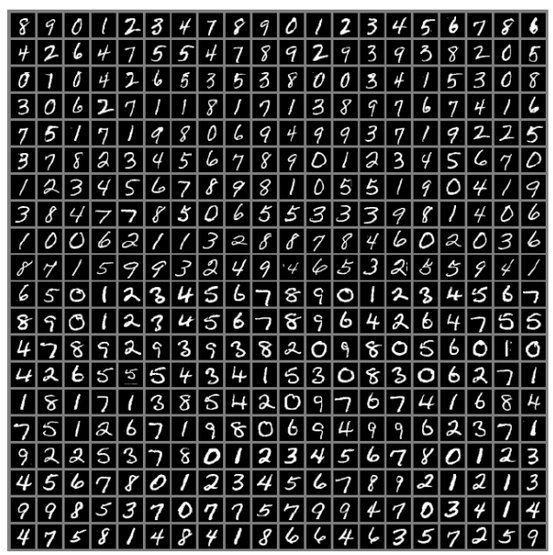
Probabilistic Generative Modeling

$$p(\mathbf{x})$$

How to express, learn, and sample from a high dimensional probability distribution ?



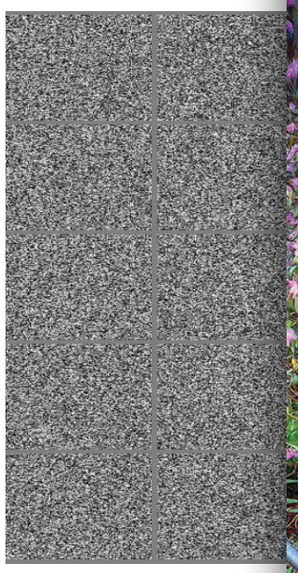
“random” images



“natural” images

Proba deling

How t e from a high d bution ?



“random

DEEP LEARNING

Ian Goodfellow, Yoshua Bengio, and Aaron Courville

Page 159

“… the images encountered in AI applications occupy a negligible proportion of the volume of image space.”

Probabilistic Generative Modeling

$$p(\mathbf{x})$$

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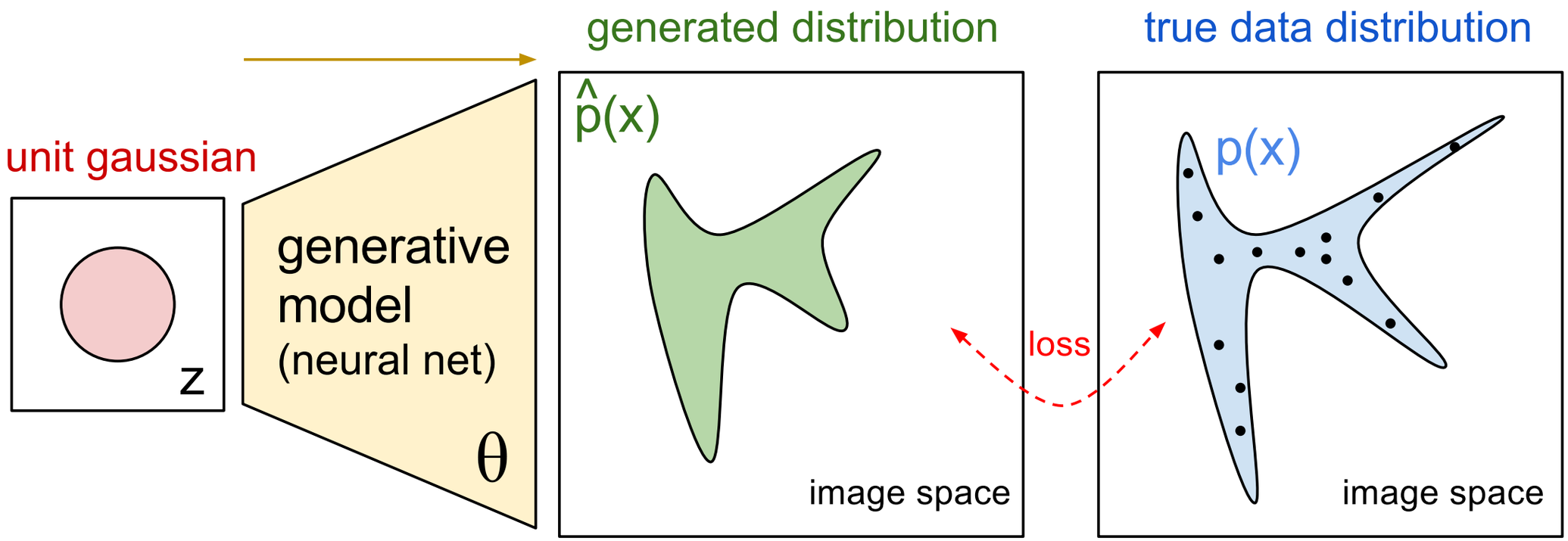
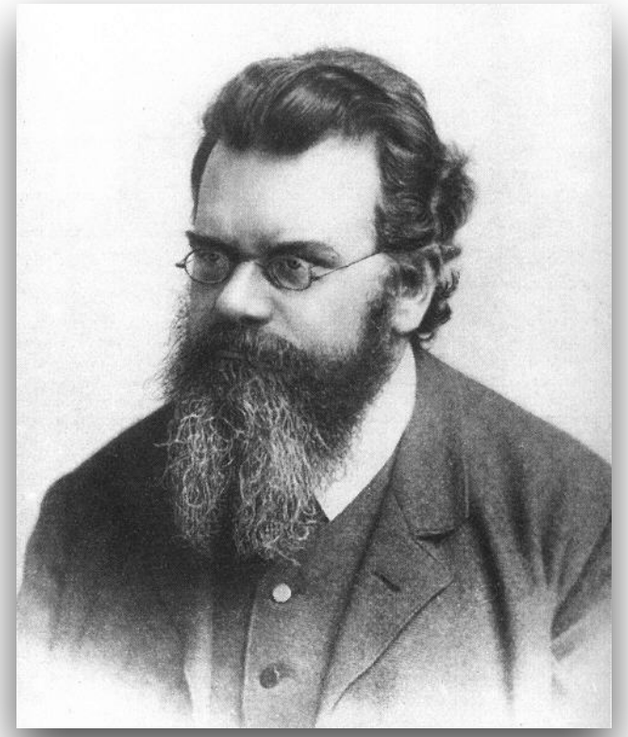


https://blog.openai.com/generative-models/

Generative Modeling and Physics



Boltzmann Machines

$$p(\mathbf{x}) = \frac{e^{-E(\mathbf{x})}}{\mathcal{Z}}$$

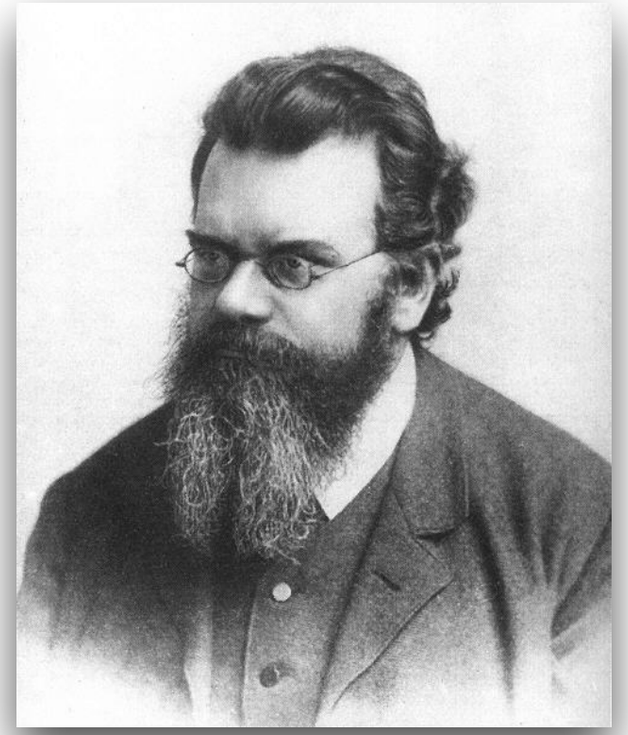
statistical physics

"Born" Machines

$$p(\mathbf{x}) = \frac{|\Psi(\mathbf{x})|^2}{\mathcal{N}}$$

quantum physics

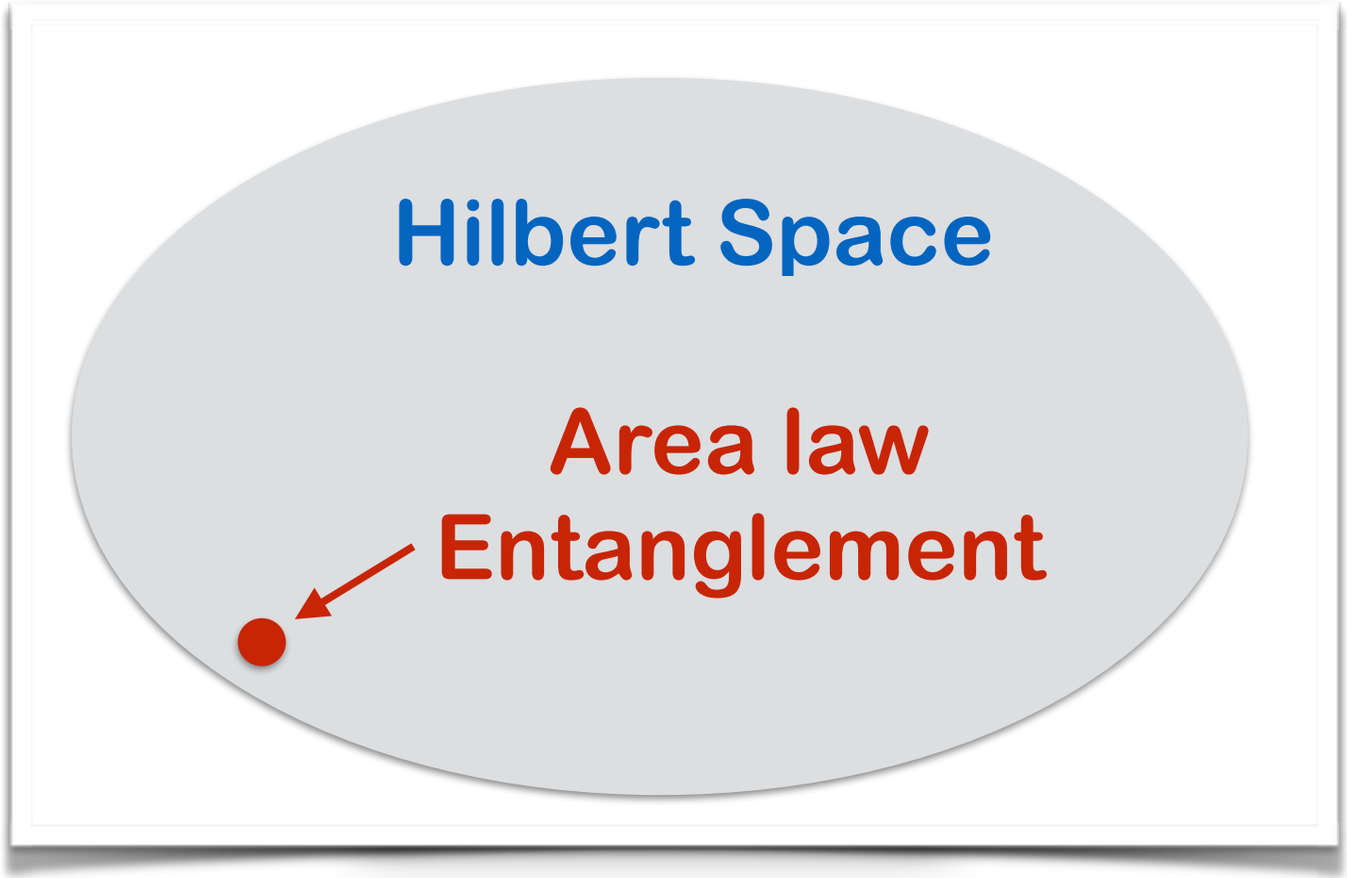
Generative Modeling and Physics



Boltzmann Machines

$$p(\mathbf{x}) = \frac{e^{-E(\mathbf{x})}}{\mathcal{Z}}$$

statistical physics



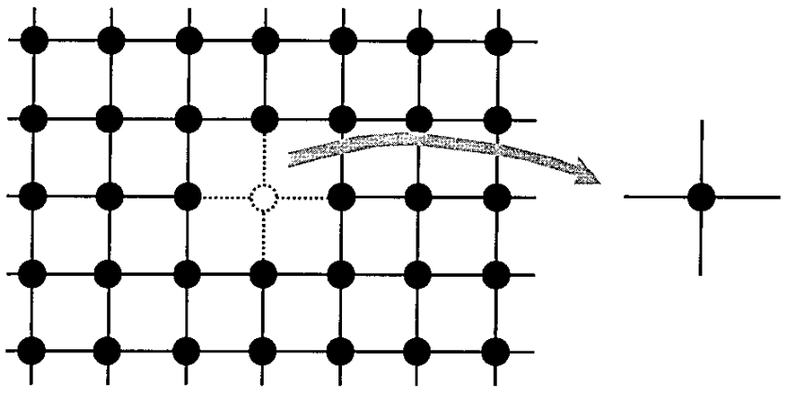
"Born" Machines

$$p(\mathbf{x}) = \frac{|\Psi(\mathbf{x})|^2}{\mathcal{N}}$$

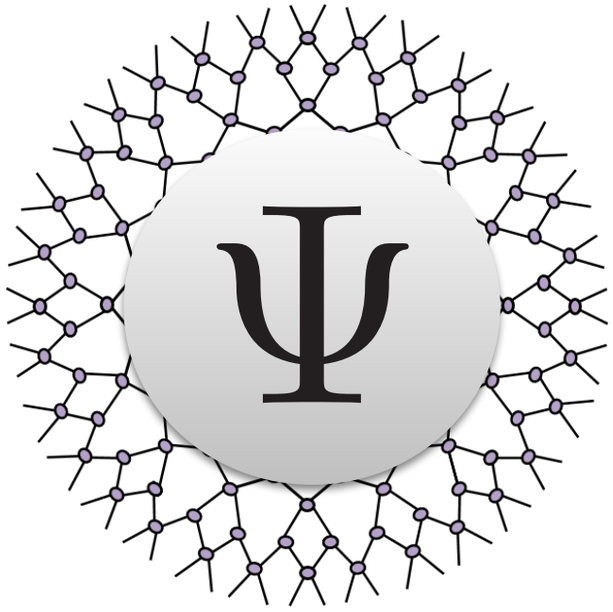
quantum physics

Gifts from Physicists

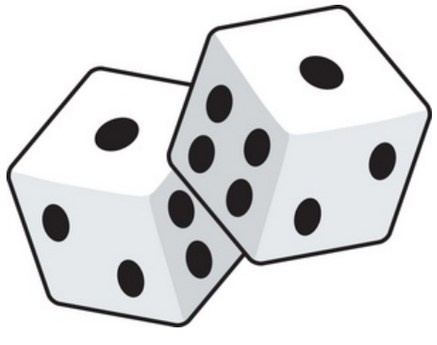
Mean Field Theory



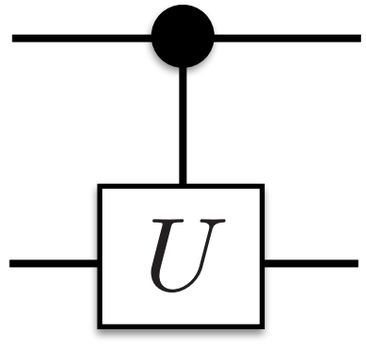
Tensor Networks



Monte Carlo Methods

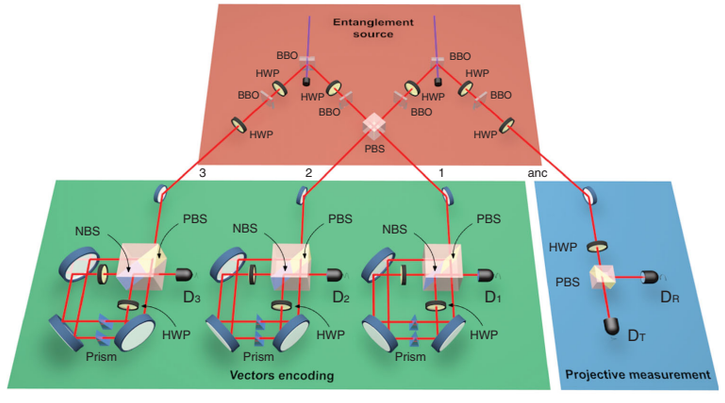


Quantum Computing



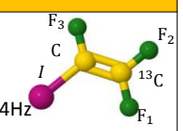
Quantum Machine Learning

- Search
- Sampling
- Clustering
- Optimization
- Linear system solver
- Support vector machines
- Principal component analysis



Cai et al, PRL **114**, 110504 (2015)

	^{13}C	F_1	F_2	F_3
^{13}C	15479.9Hz			
F_1	-297.7Hz	-33130.1Hz		
F_2	-275.7Hz	64.6Hz	-42681.4Hz	
F_3	39.1Hz	51.5Hz	-129.0Hz	-56443.5Hz
T_2^*	1.22s	0.66s	0.63s	0.61s
T_2	7.9s	4.4s	6.8s	4.8s



Li et al, PRL **114**, 140504 (2015)

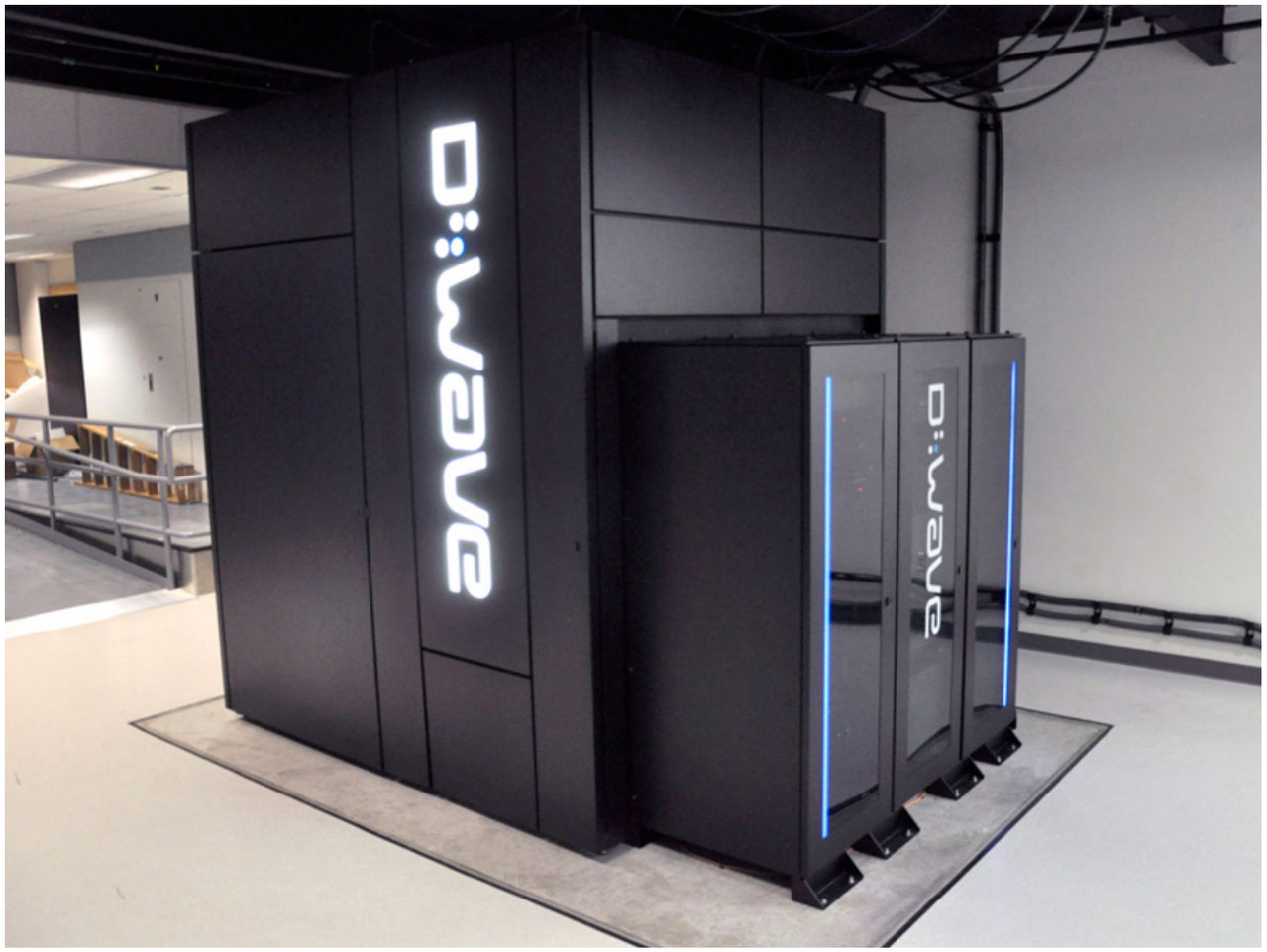
few qubits demo

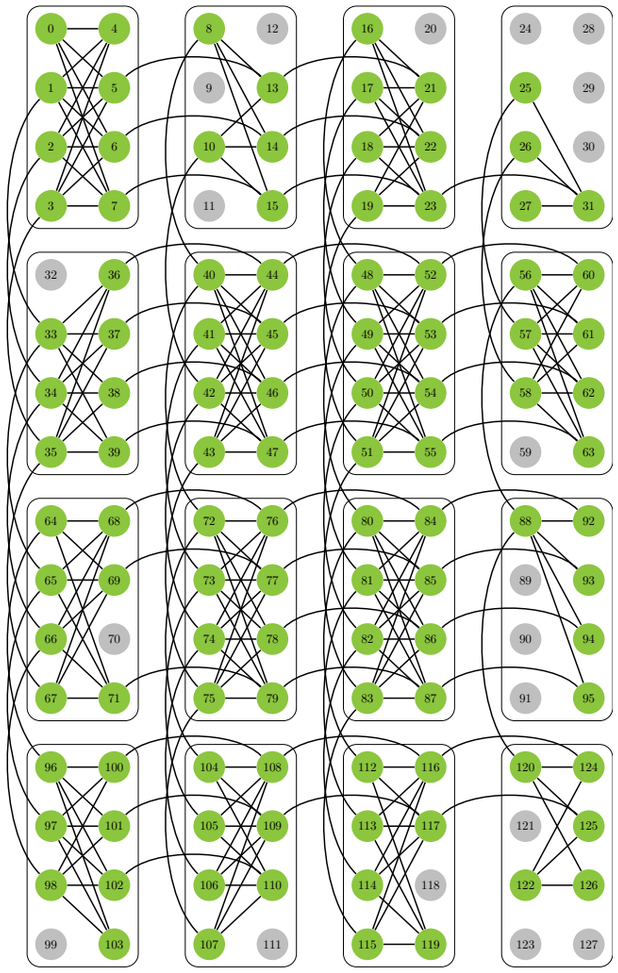
“Use a quantum computer to speed up ML subroutines”

Review “Quantum machine learning”, Biamonte et al, Nature 2017

Quantum Boltzmann Machines

$15 million "analog quantum device"





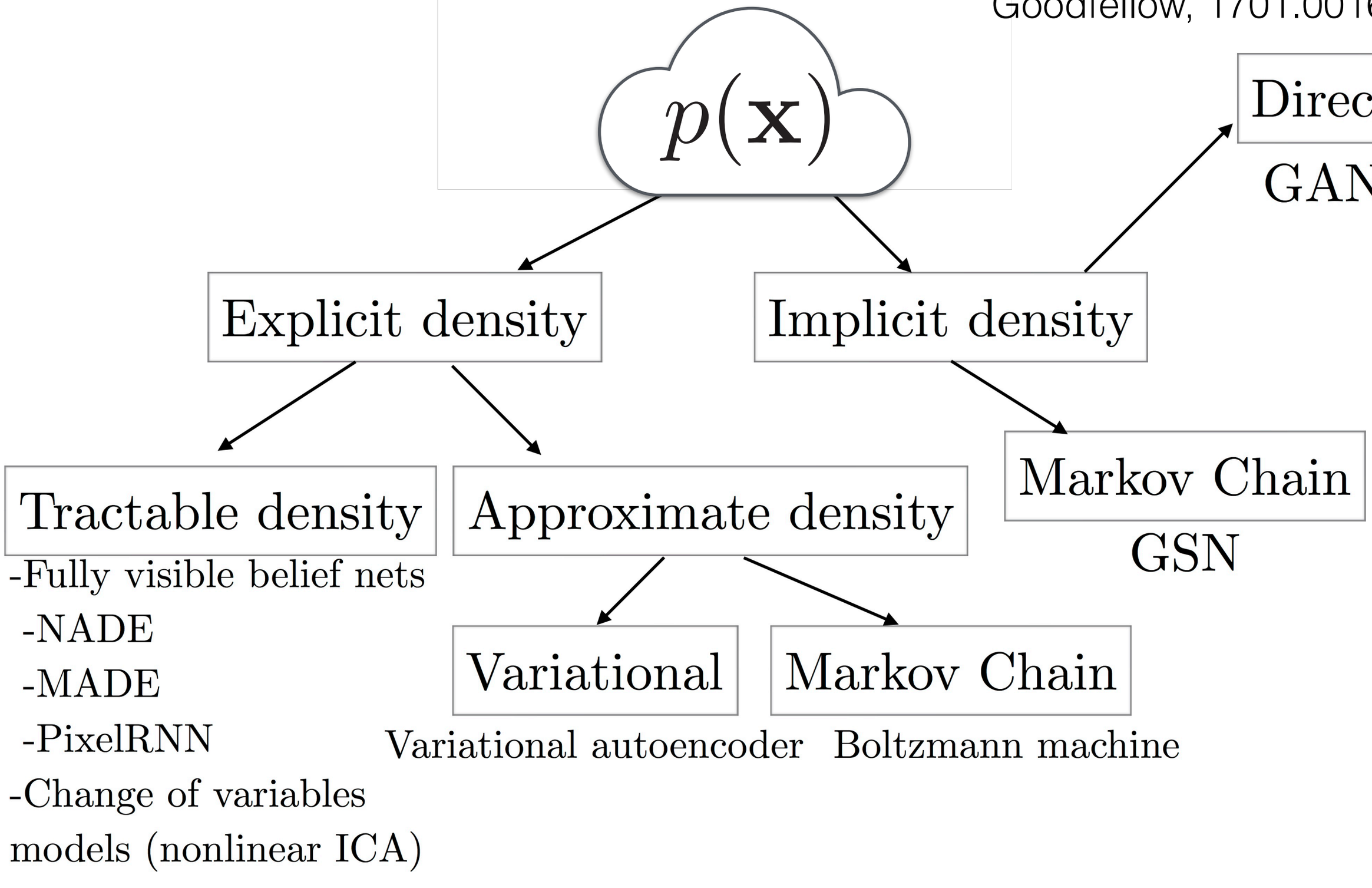
~2000
"qubits"

Is there any advantage of this quantum architecture?

Amin et al, 1601.02036 Perdomo-Ortiz et al, 1708.09757

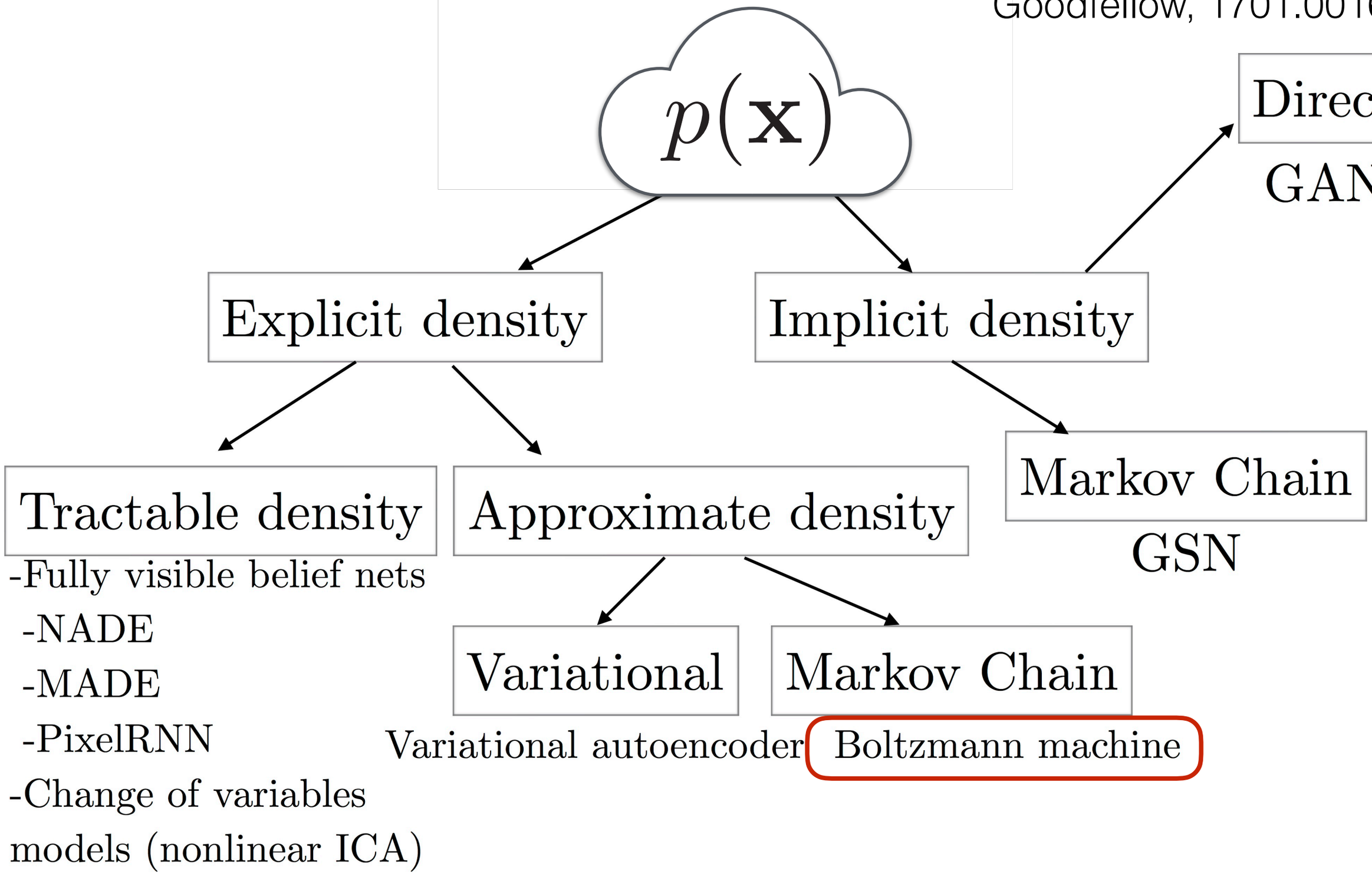
Taxonomy of Generative Models

Goodfellow, 1701.00160



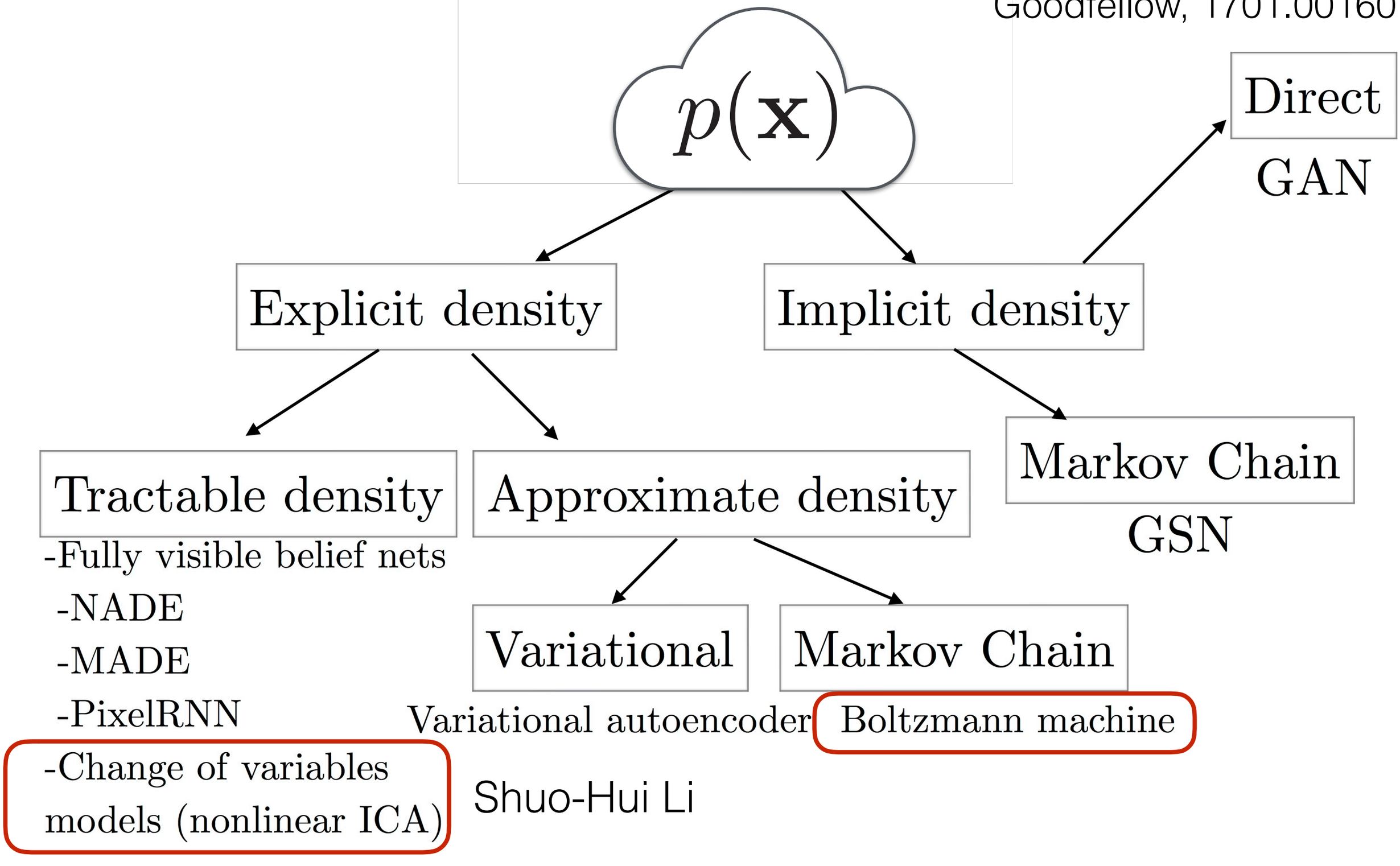
Taxonomy of Generative Models

Goodfellow, 1701.00160



Taxonomy of Generative Models

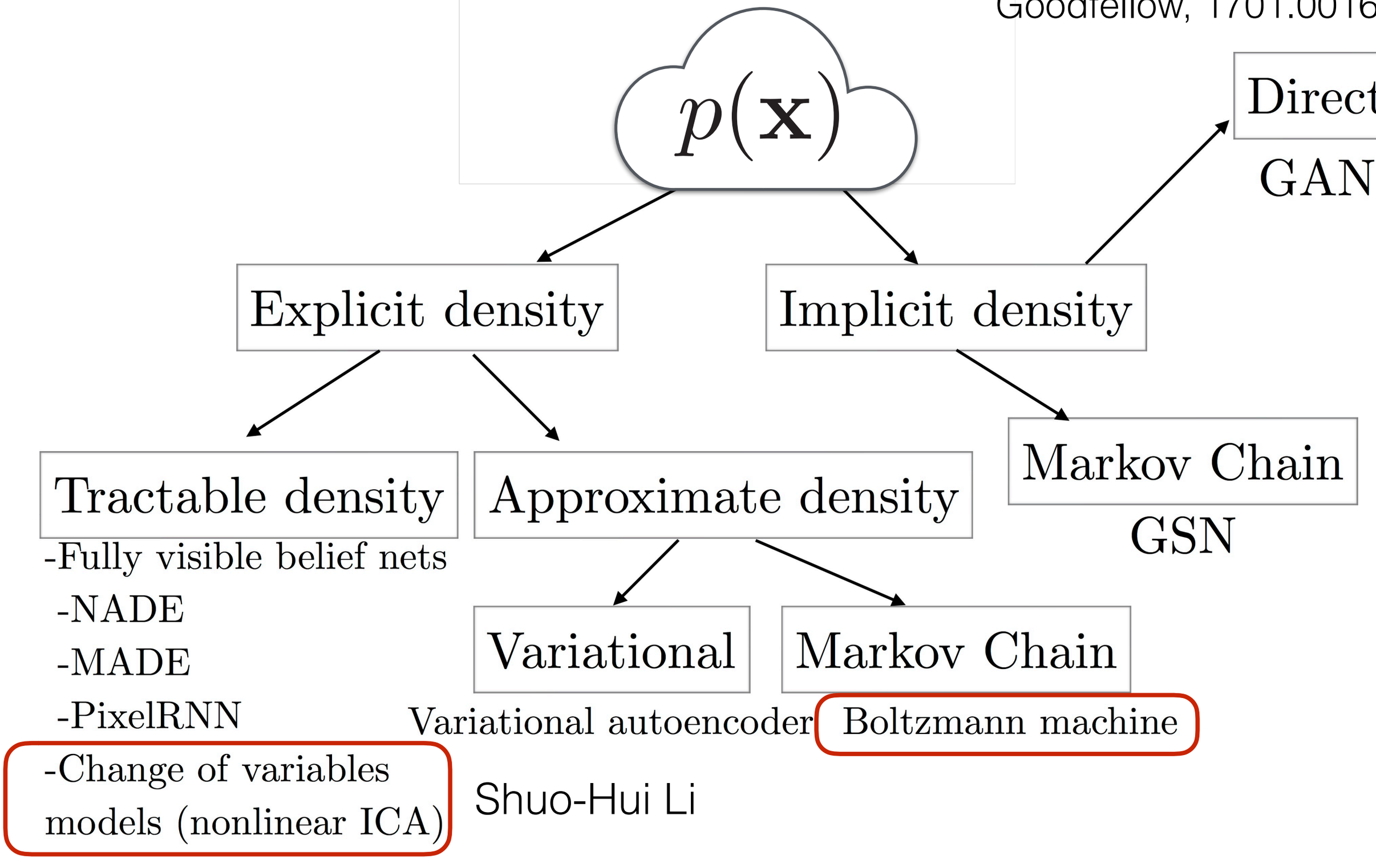
Goodfellow, 1701.00160



Shuo-Hui Li

Taxonomy of Generative Models

Goodfellow, 1701.00160



+Matrix Product States Jun Wang, Zhao-Yu Han

Taxonomy of Generative Models

Goodfellow, 1701.00160