Neural NILM

Deep Neural Networks Applied To Energy Disaggregation

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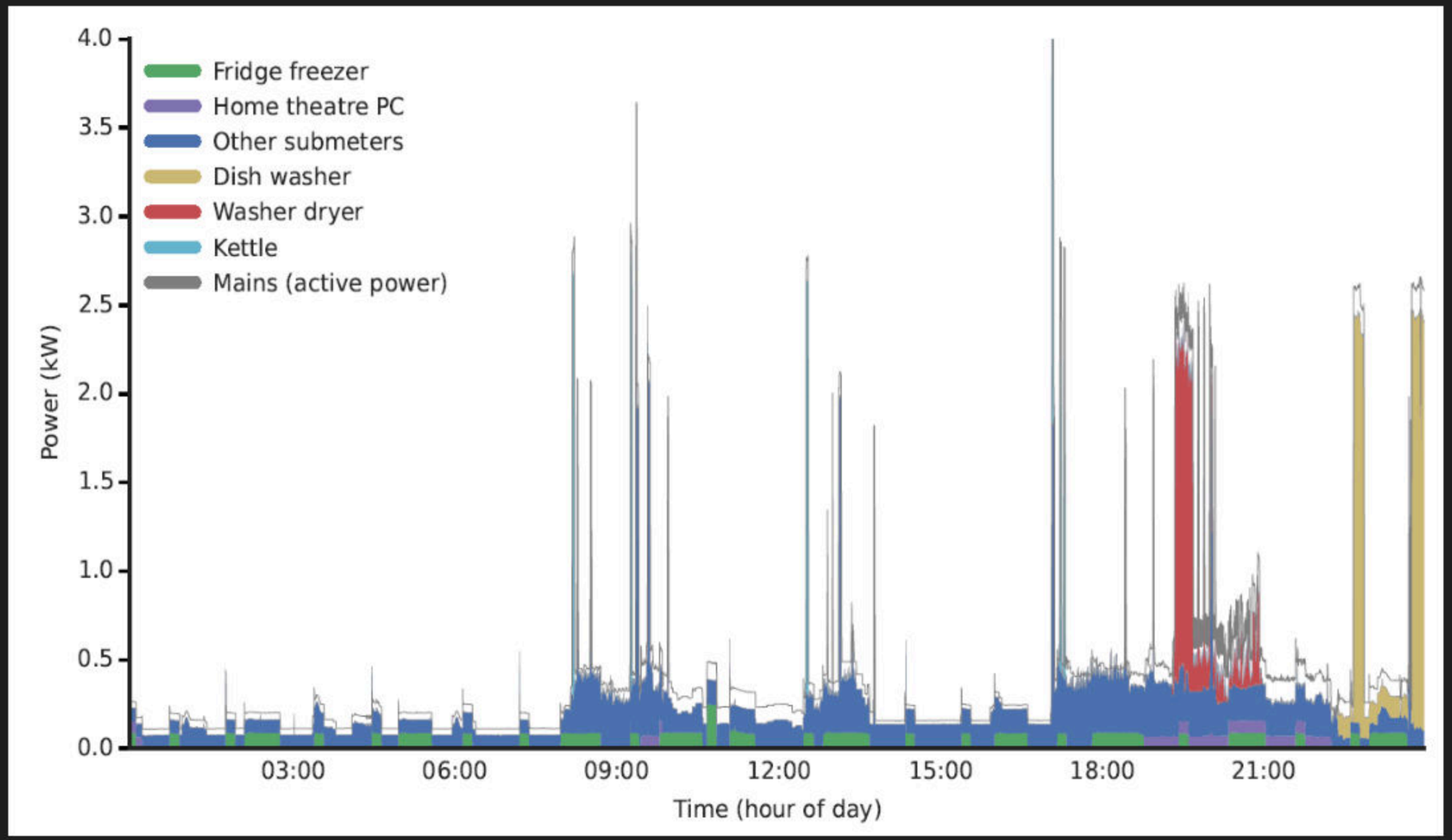
Imperial College London

(View this presentation at jackkelly.github.io/EPRI_NeuralNILM to see the animations)

Also see my paper:
Kelly & Knottenbelt. **Neural NILM: Deep Neural Nets Applied to Energy Disaggregation**. *BuildSys* 2015

Energy Disaggregation



Outline

1. Why use deep neural nets (DNNs) for NILM?
2. How DNNs work
3. Three DNN architectures for NILM
4. Data augmentation
5. Results
6. Summary

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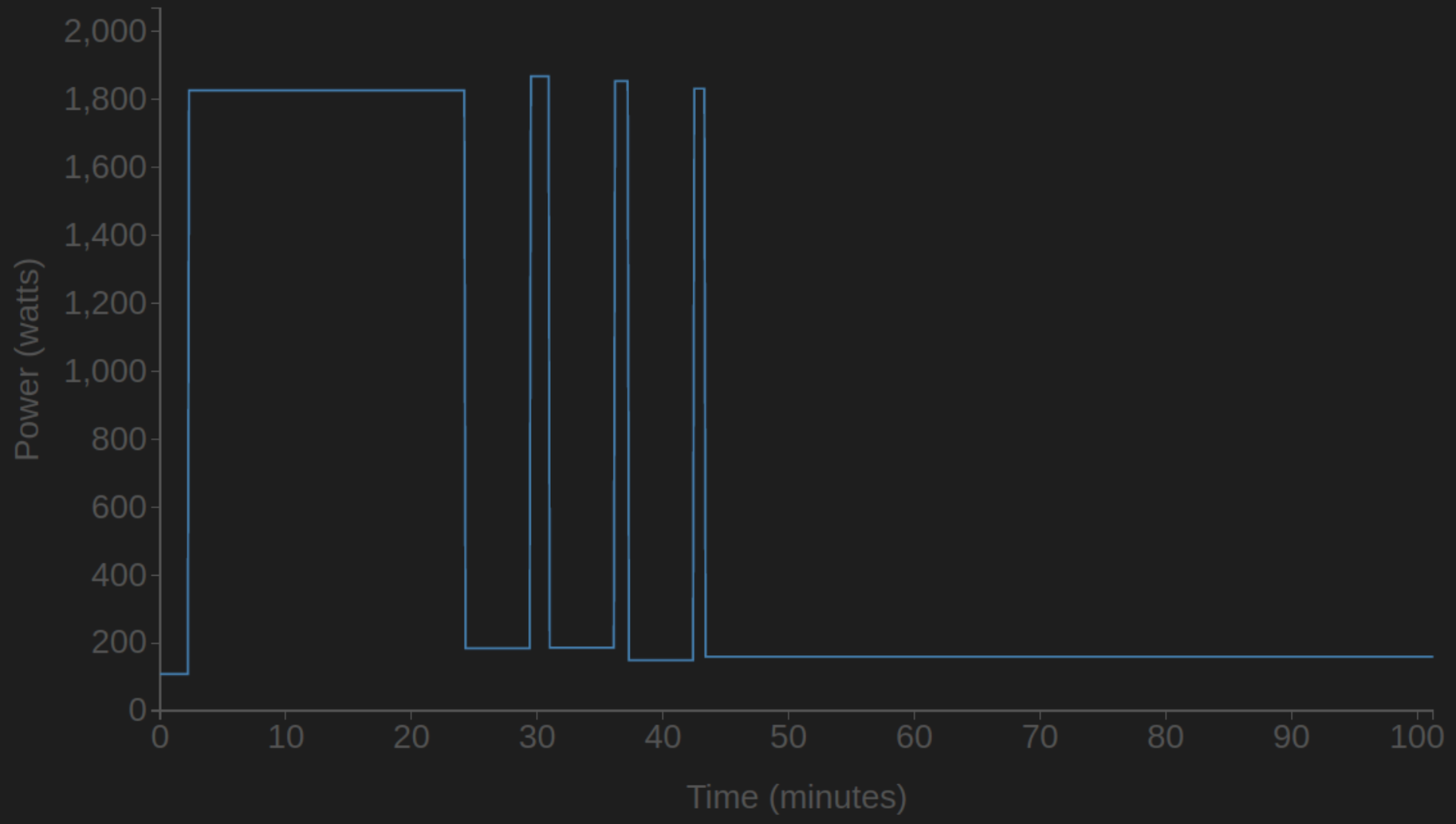
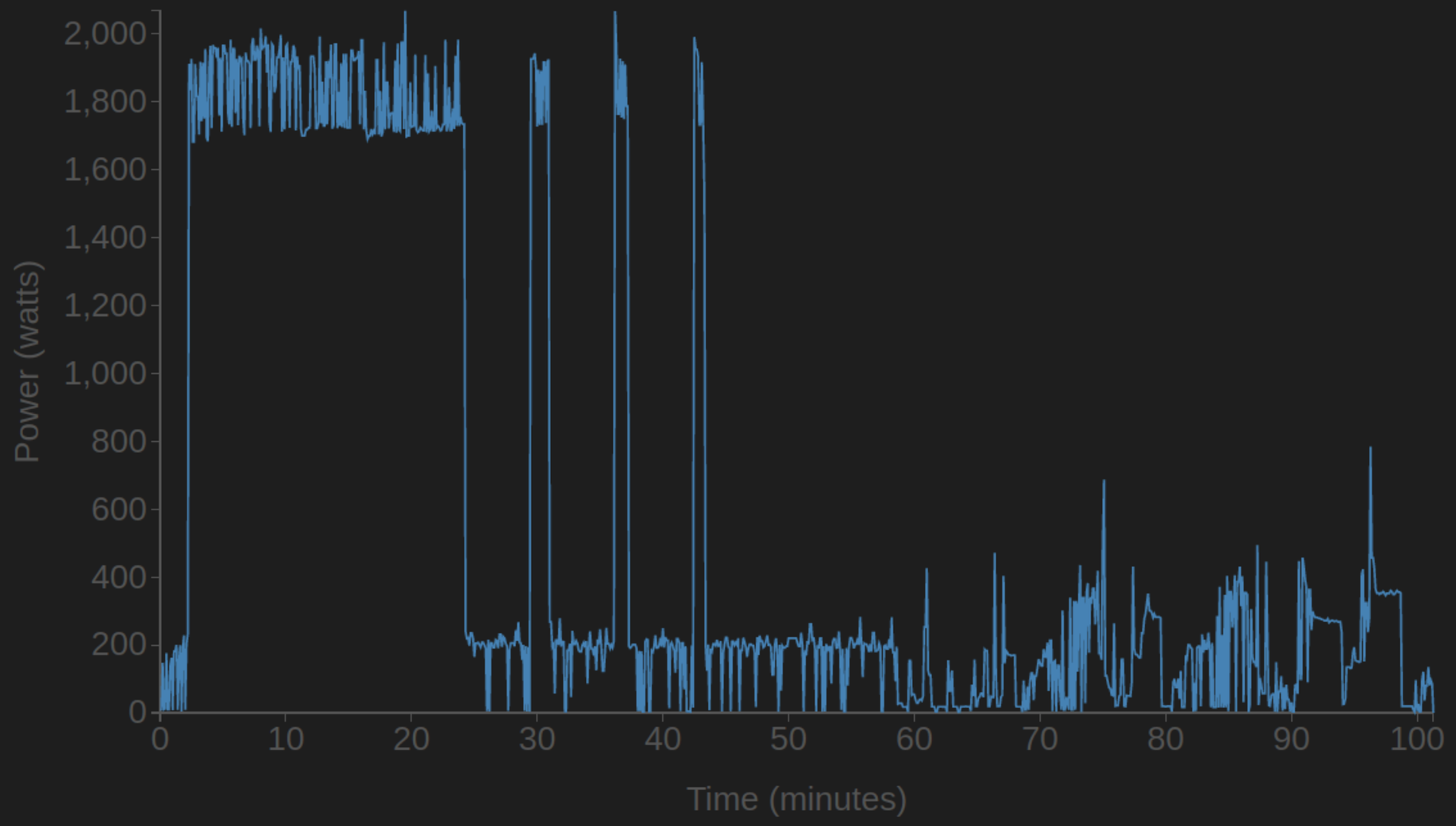
Name the Appliance?



Name the Appliance?

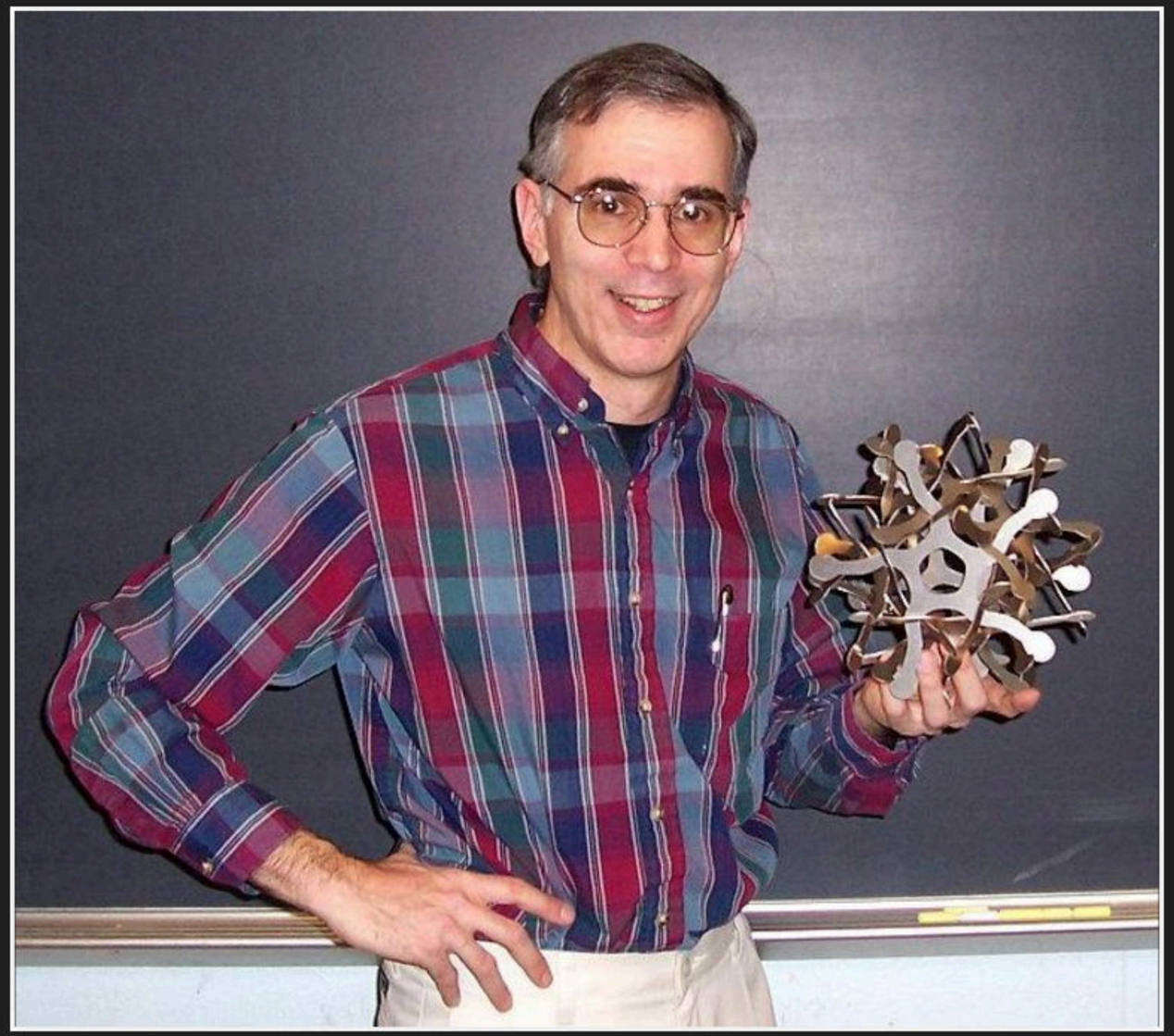


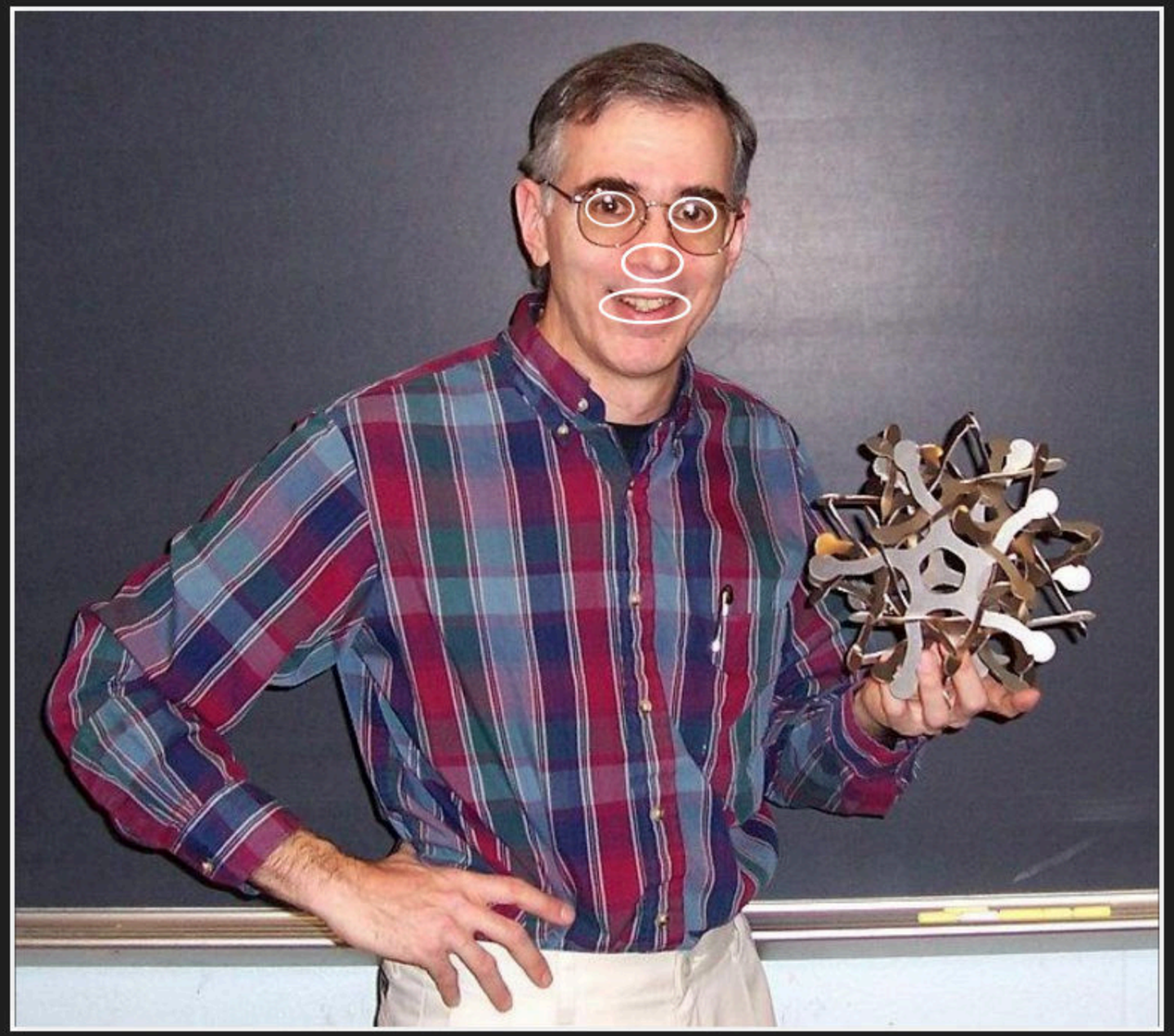
Miele

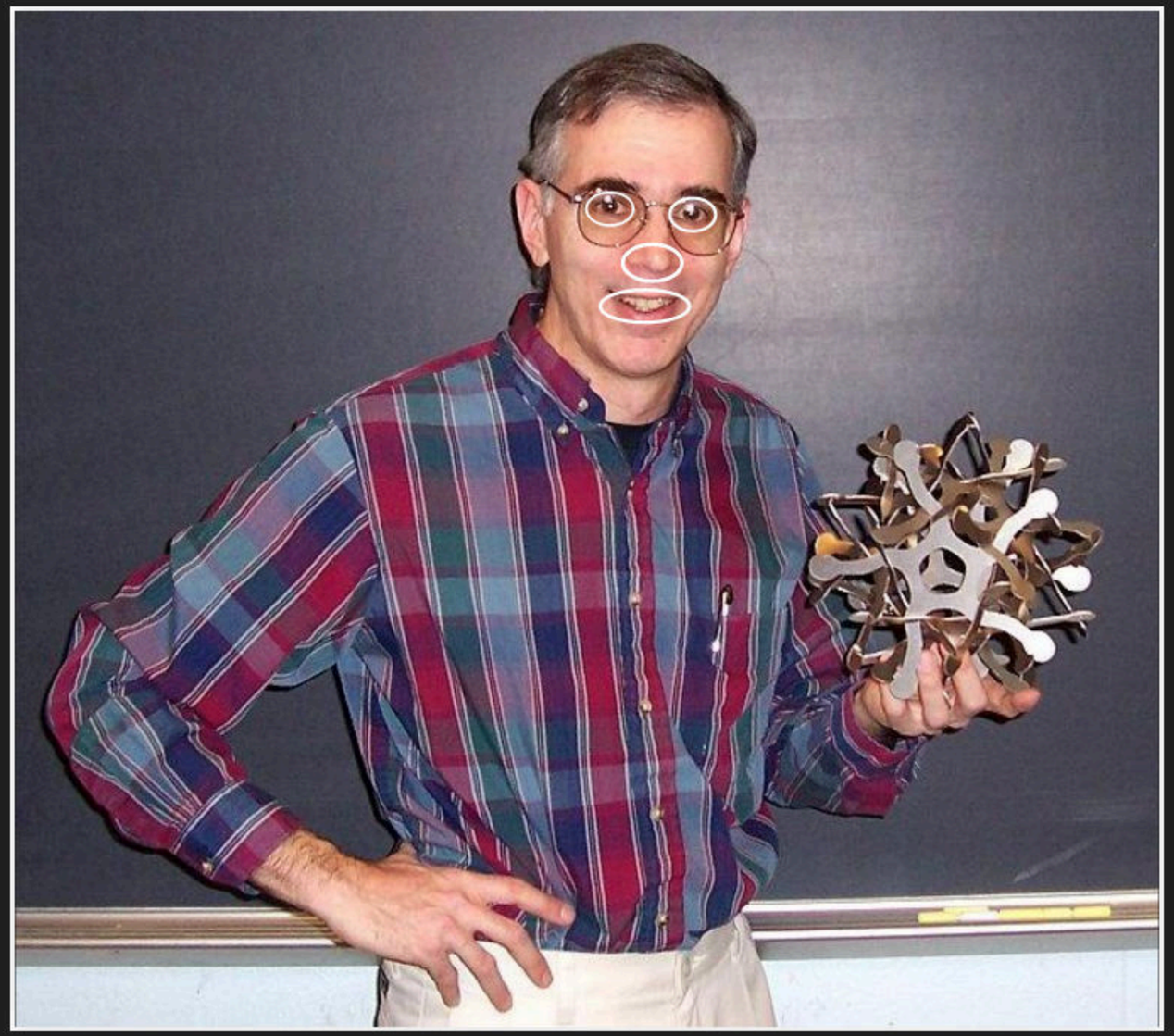
Face Recognition

Face Recognition

Manual Feature Extraction







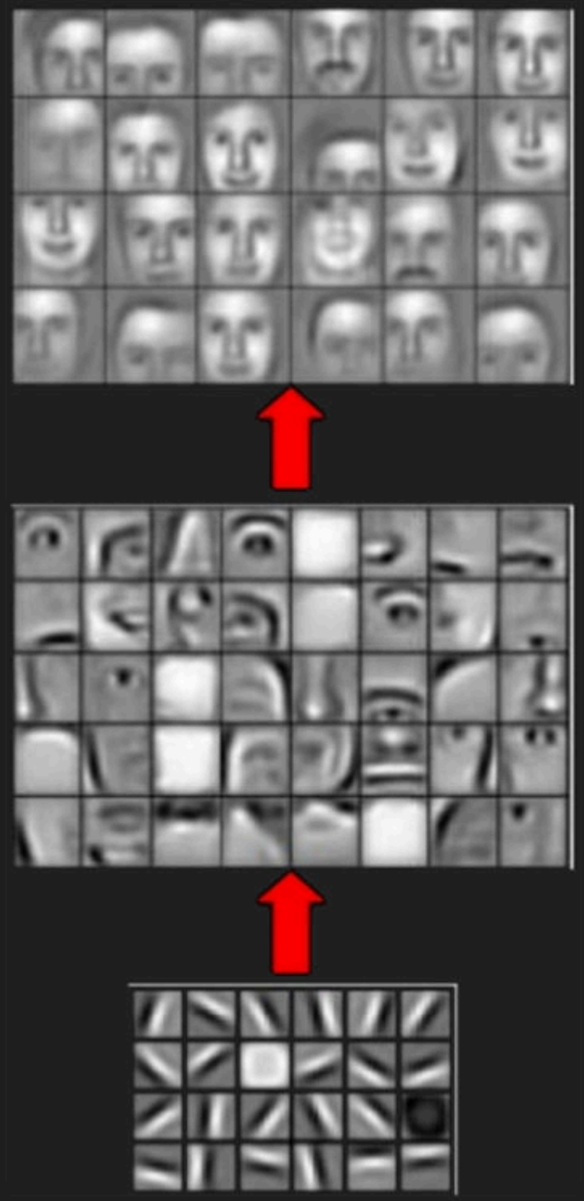
georgehart.com/research/hartbiog.html

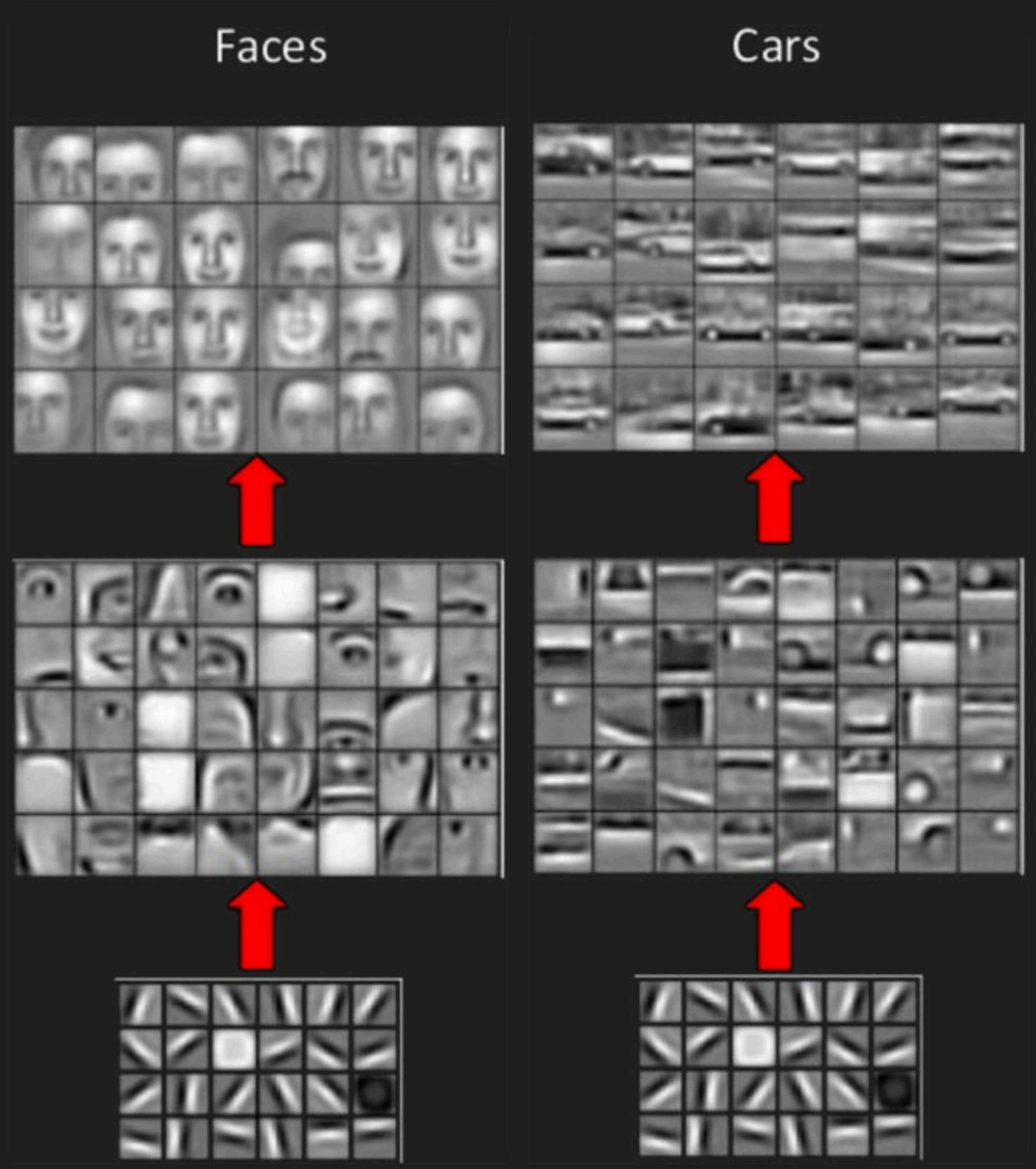
scgp.stonybrook.edu/archives/8516

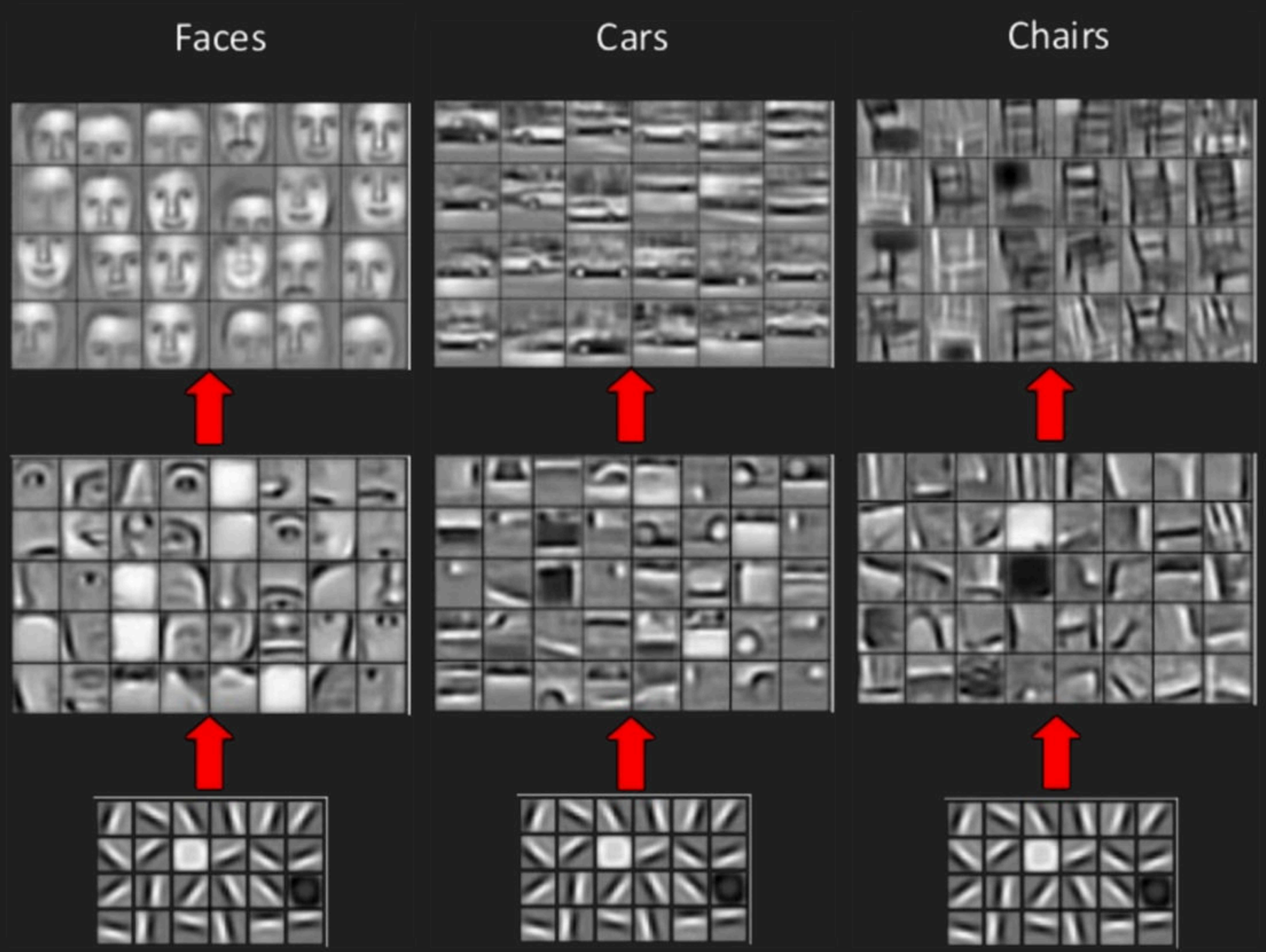
Deep Neural Nets

Automatic Feature Learning

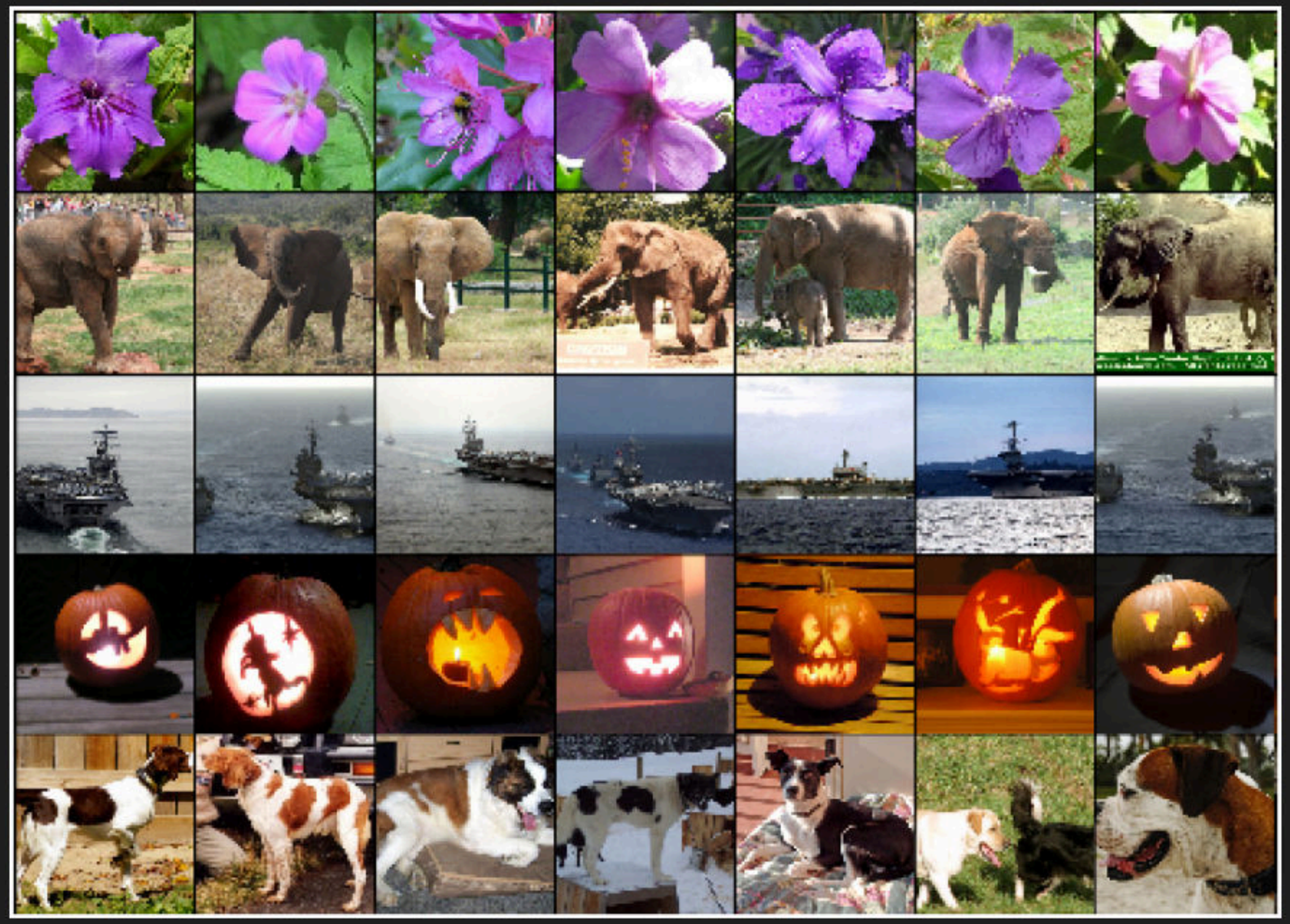
Faces




Faces
Cars


Faces
Cars
Chairs

ImageNet Large Scale Visual Recognition Challenge (ILSVRC)



From: Krizhevsky, Sutskever & Hinton. ImageNet Classification with Deep Convolutional Neural Networks. NIPS (2012)

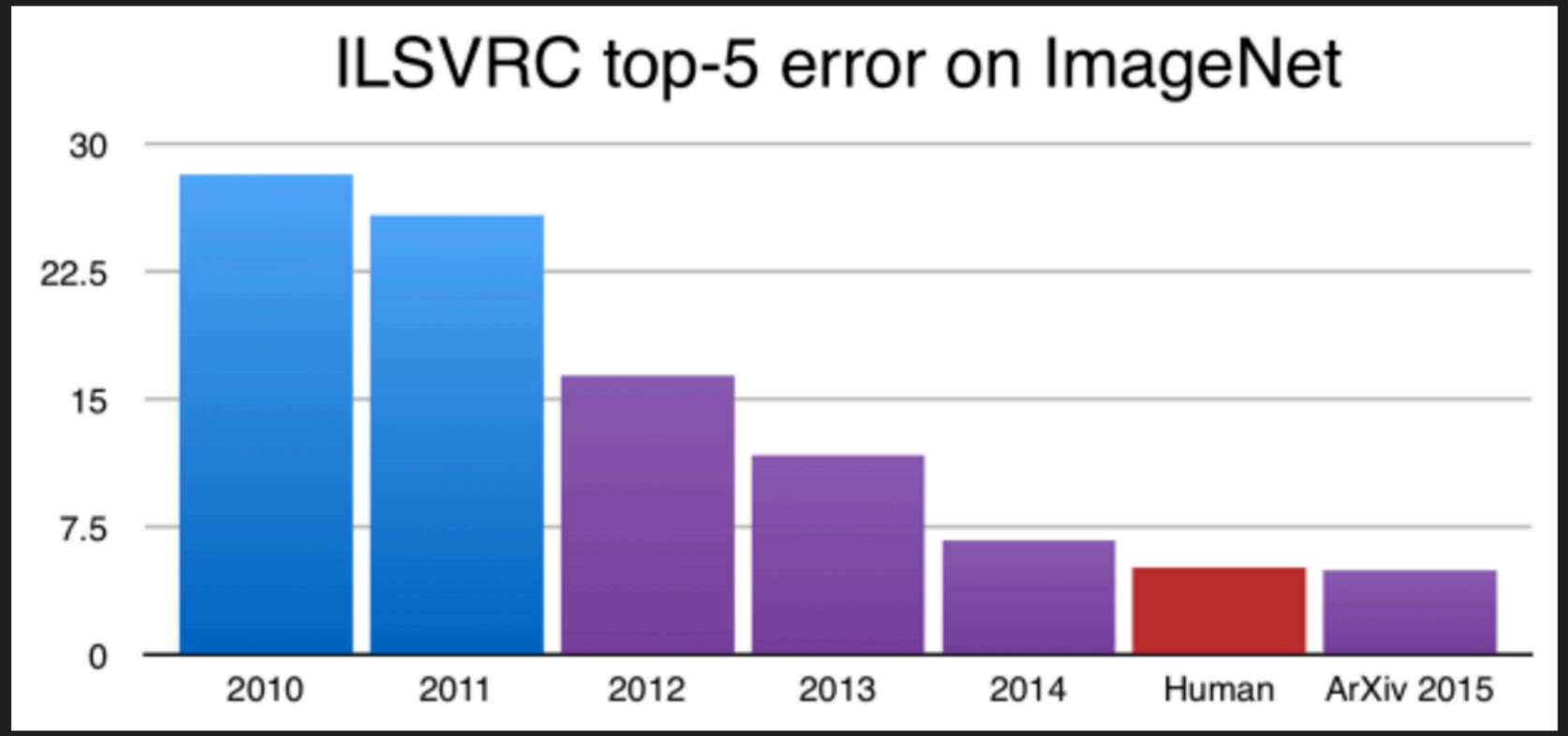
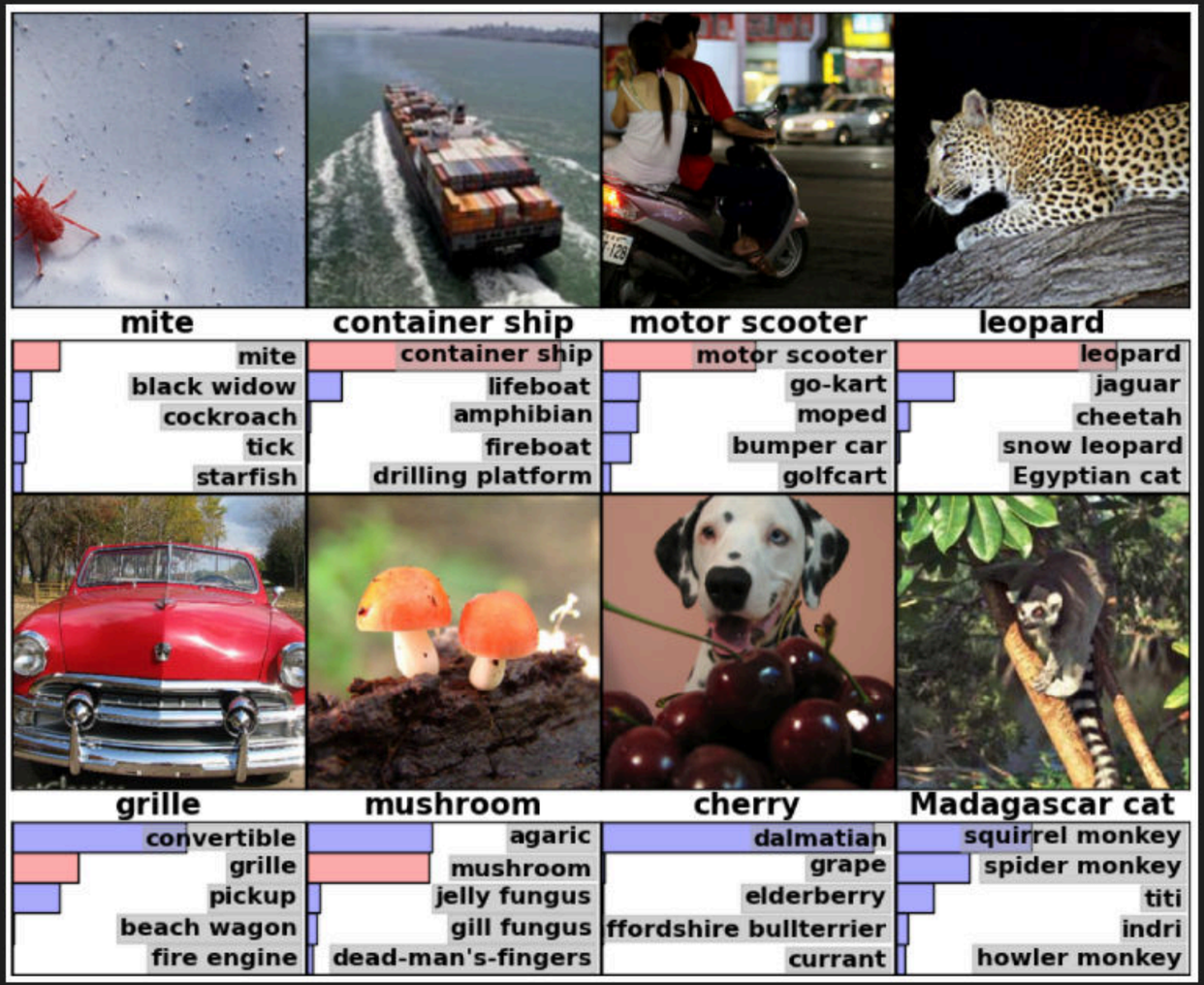


Image from devblogs.nvidia.com

Krizhevsky *et al.*'s DNN Results on ImageNet 2012



Krizhevsky, Sutskever & Hinton. ImageNet Classification with Deep Convolutional Neural Networks. NIPS (2012)

Outline

1. Why use deep neural nets (DNNs) for NILM?
2. How DNNs work
3. Three DNN architectures for NILM
4. Data augmentation
5. Results
6. Summary

The Artificial Neuron

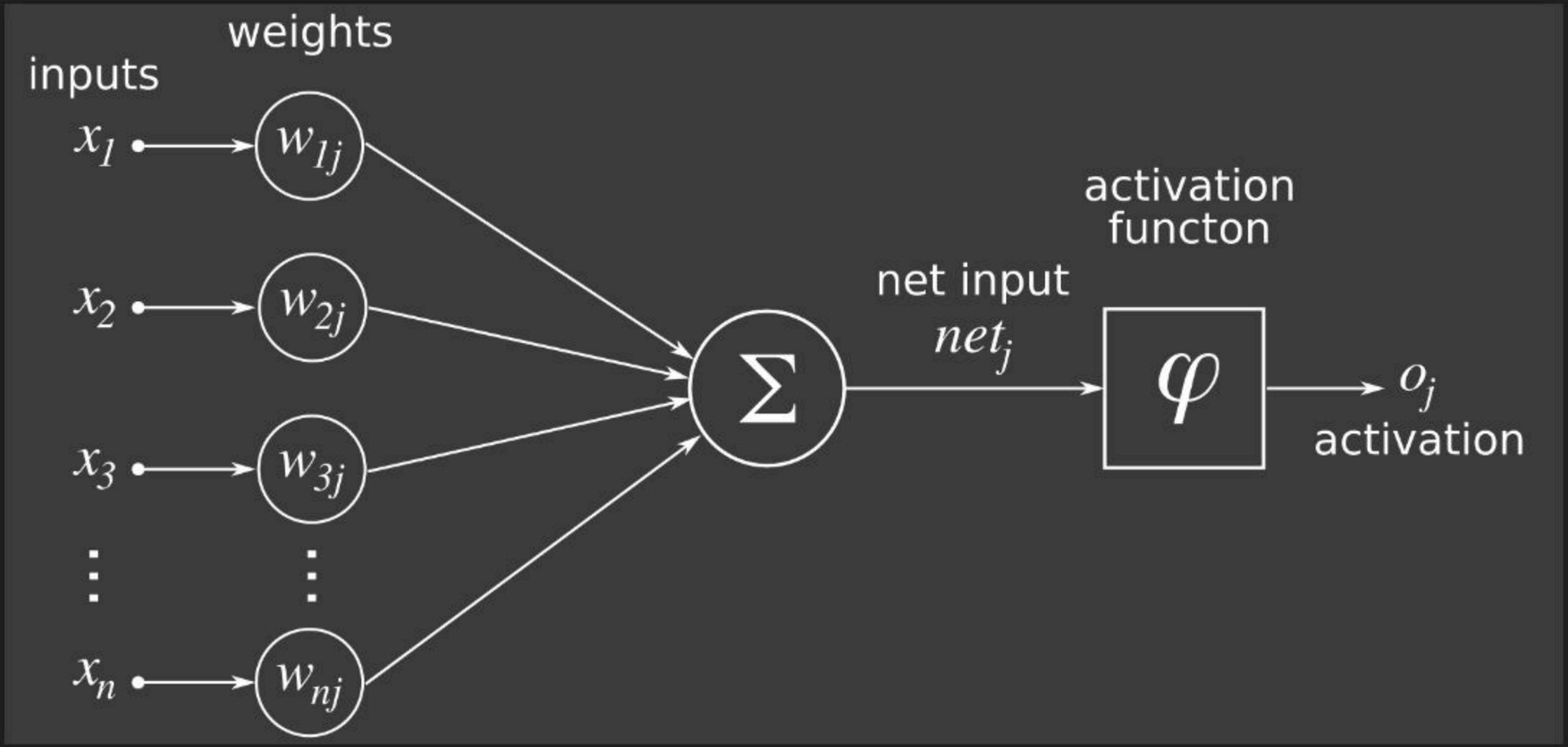
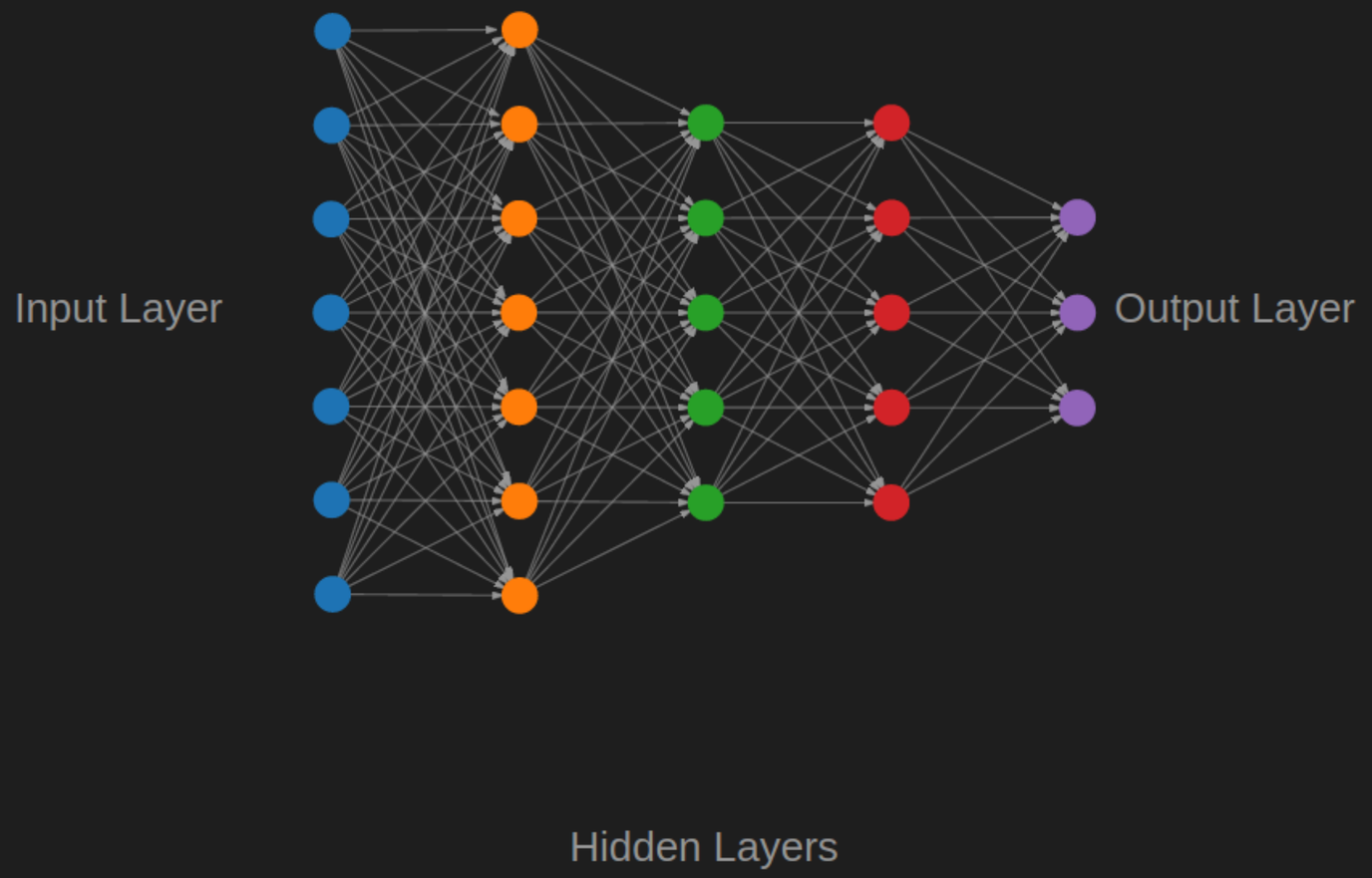
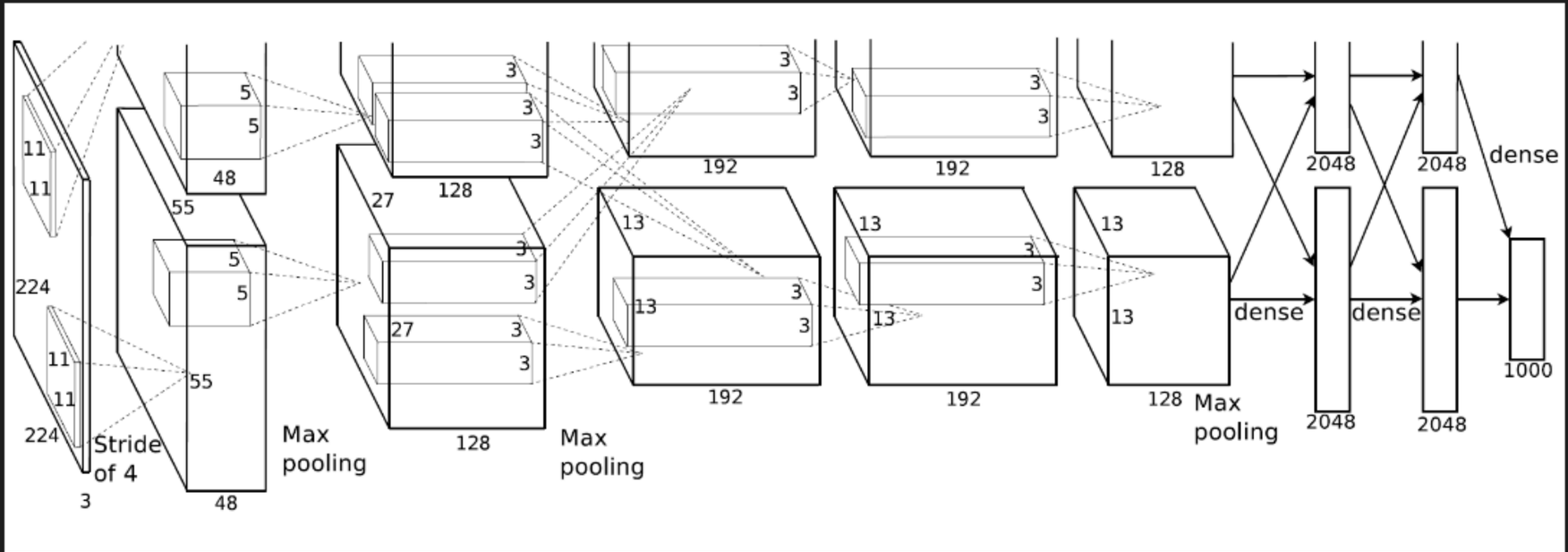


Image adapted from WikiMedia Commons image by Chrislb

Feed Forward Nets

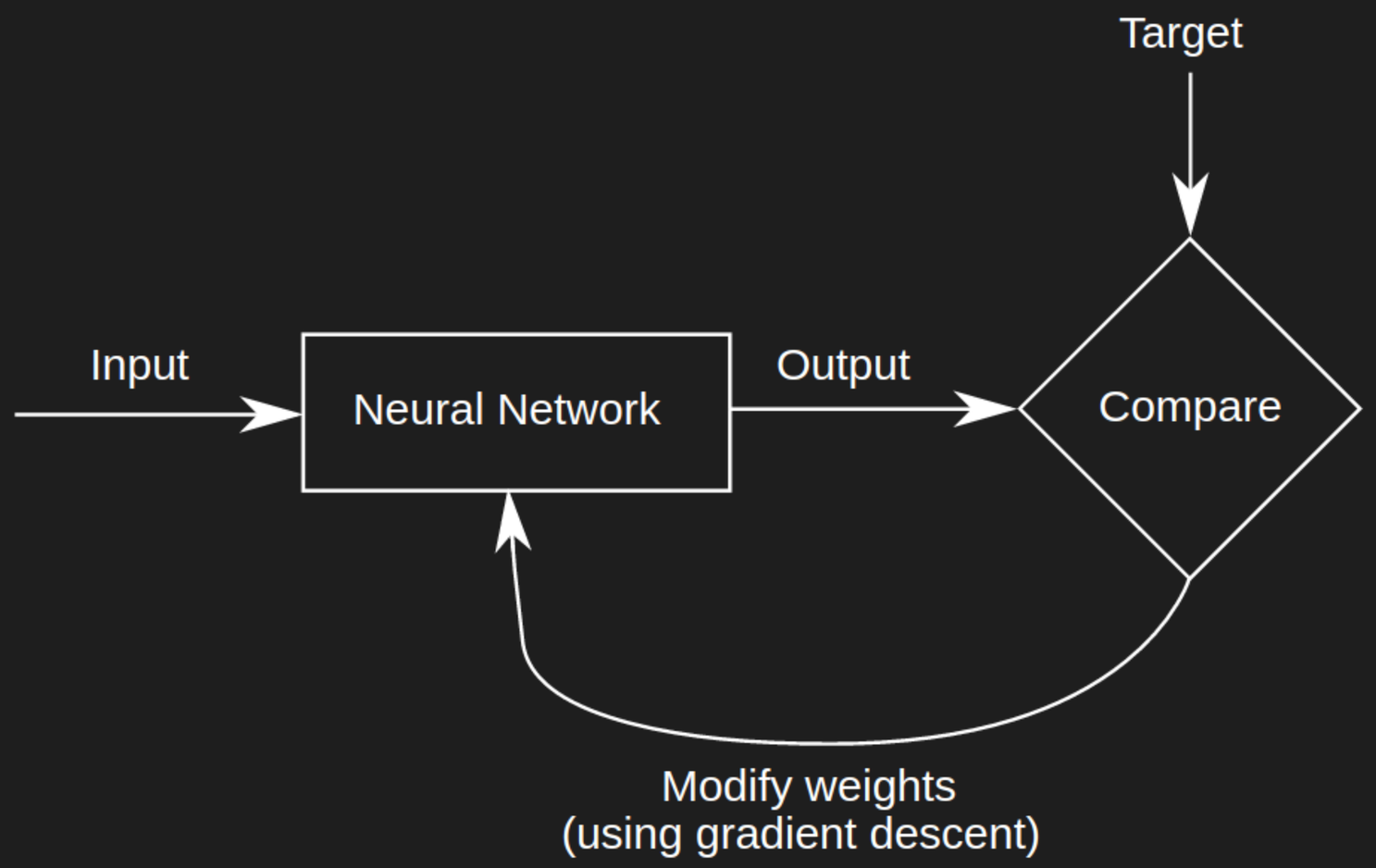


Krizhevsky et al.'s Architecture for ImageNet 2012

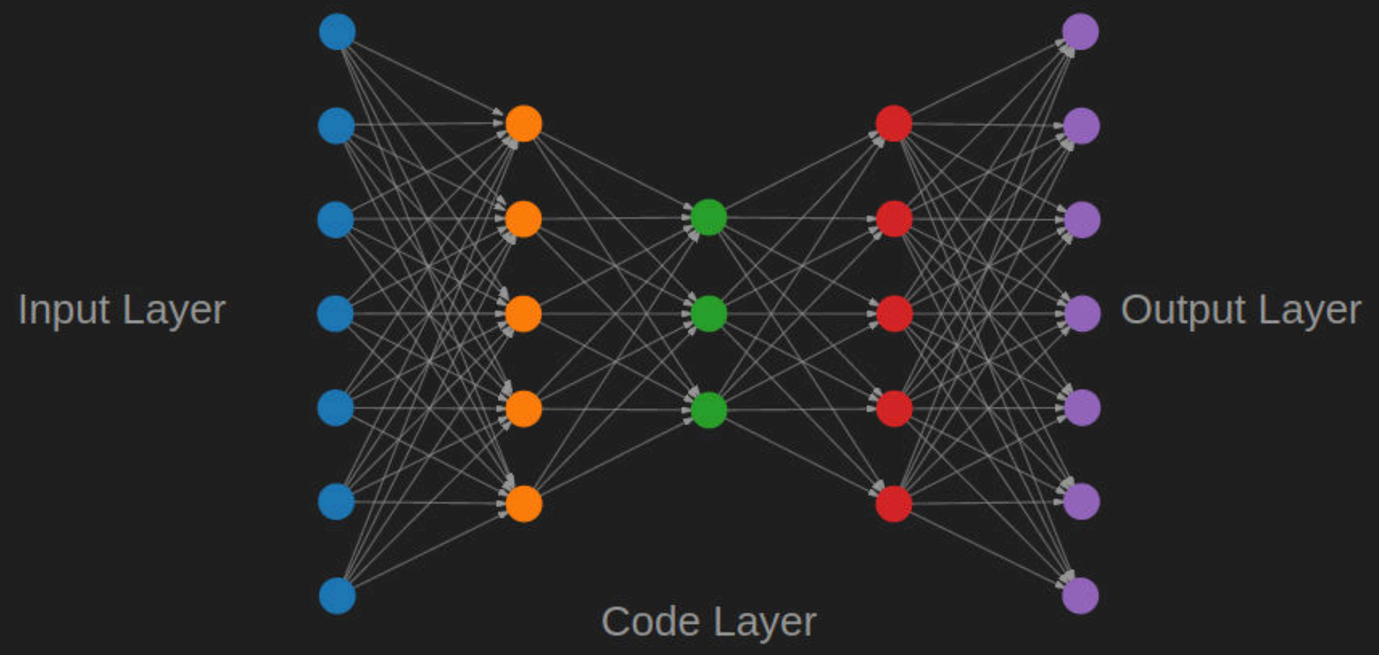


Krizhevsky, Sutskever & Hinton. ImageNet Classification with Deep Convolutional Neural Networks. NIPS (2012)

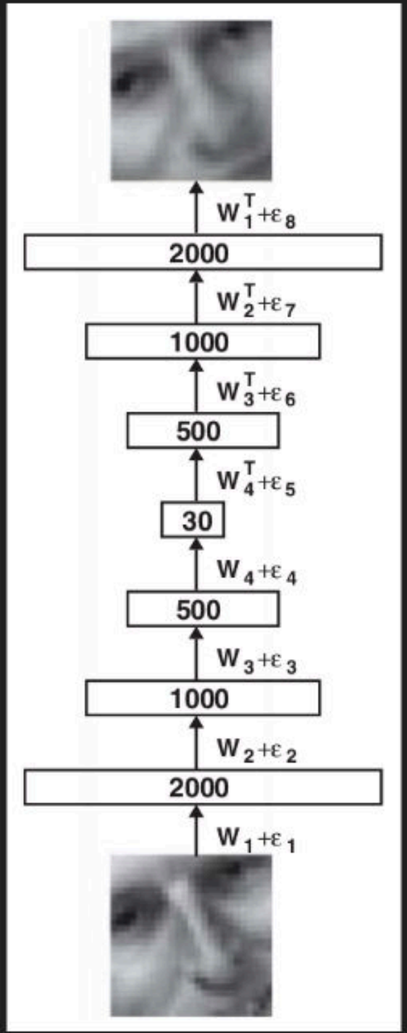
Training


Target
Input
Neural Network
Output
Compare
Modify weights
(using gradient descent)

Autoencoders

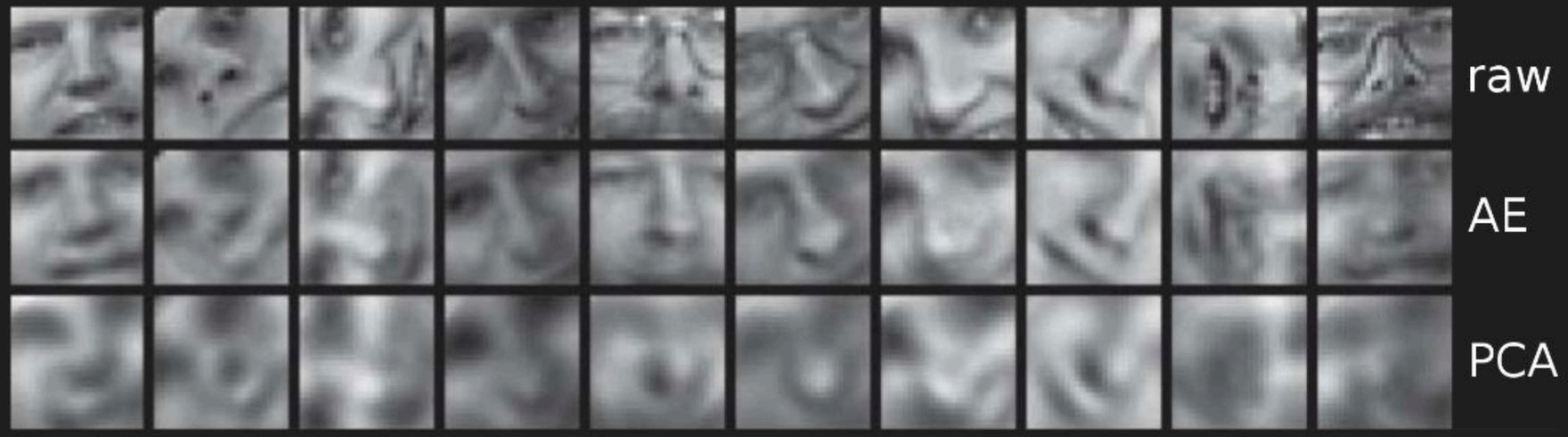


Autoencoder Examples



Hinton & Salakhutdinov. **Reducing the dimensionality of data with neural networks.** *Science* (2006)

Autoencoder Examples



Hinton & Salakhutdinov. **Reducing the dimensionality of data with neural networks.** *Science* (2006)

Denoising Autoencoders

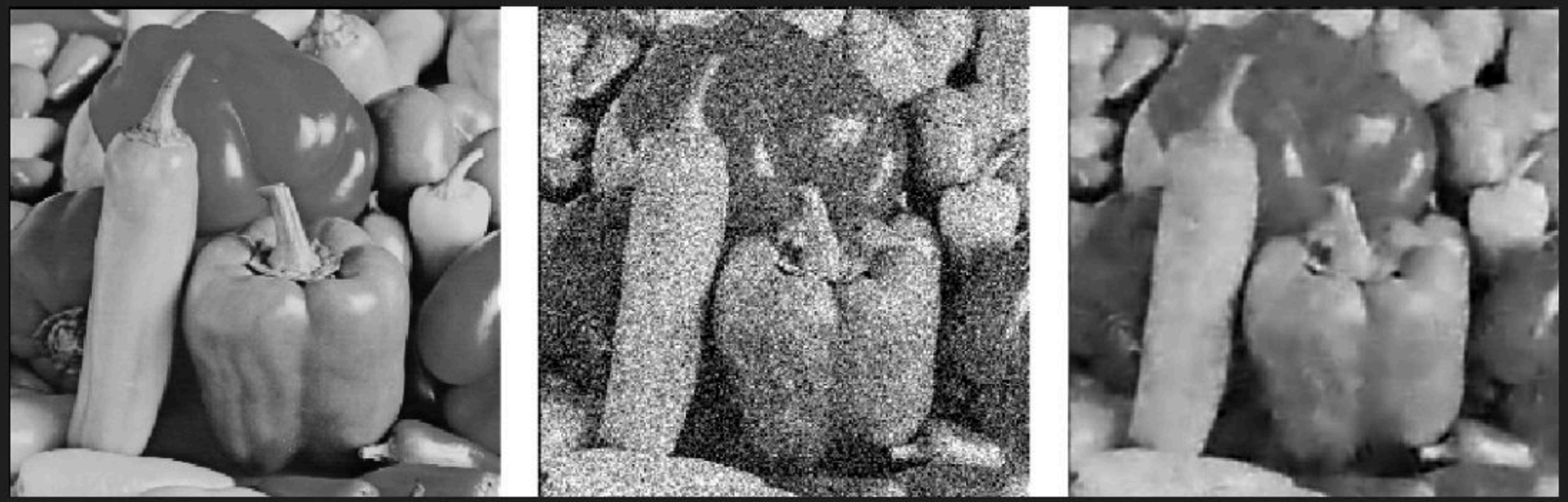
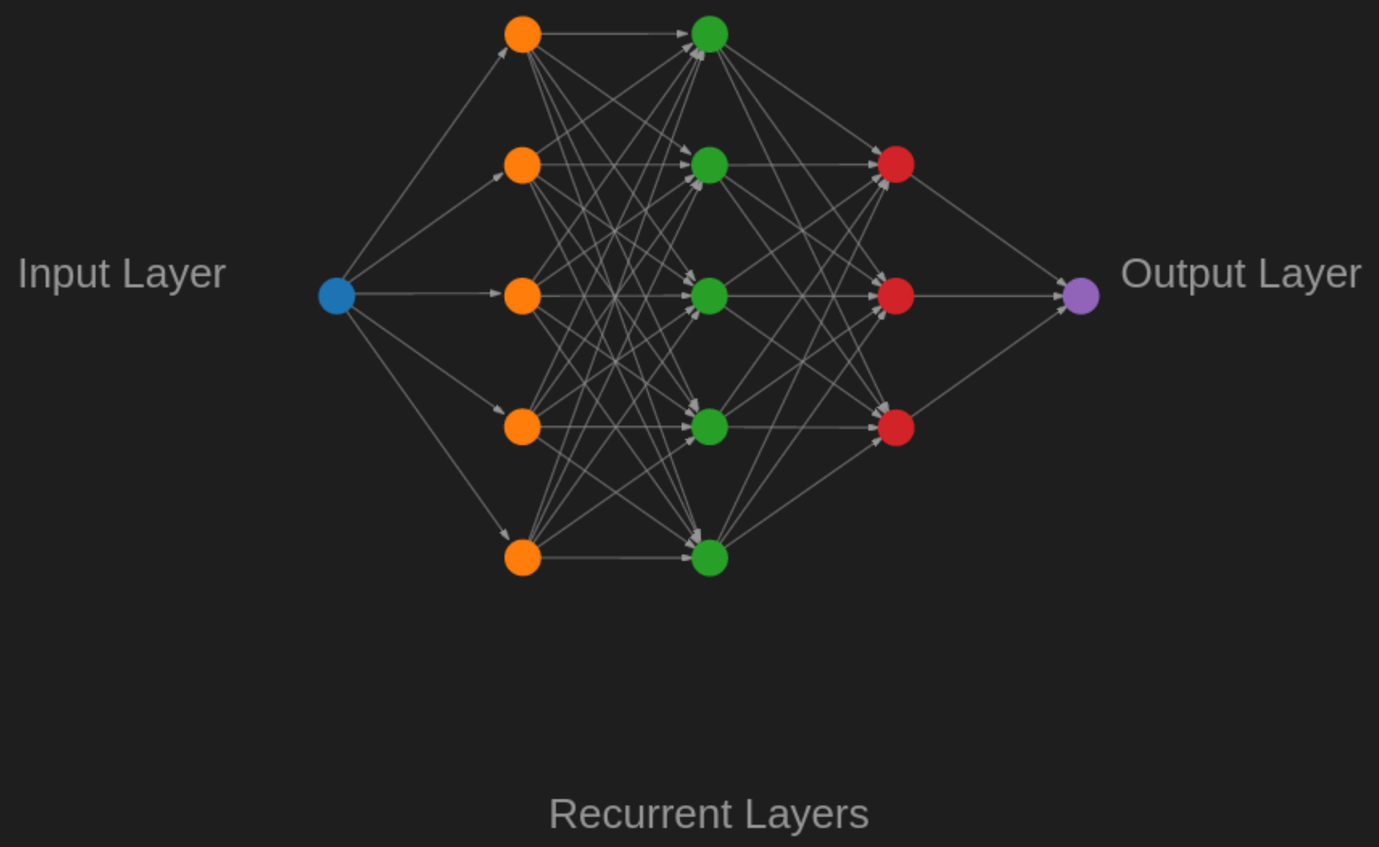


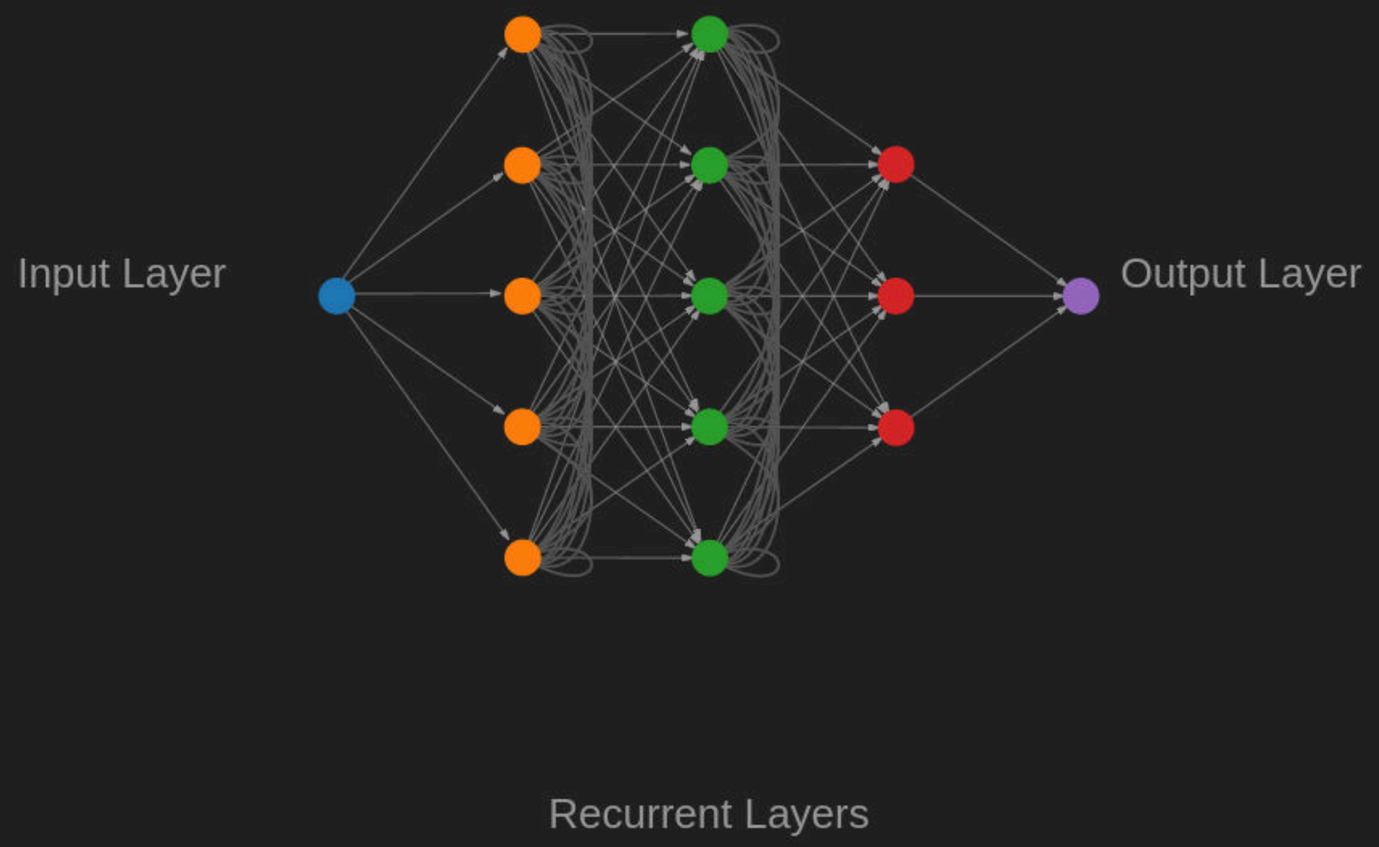
Image from Marc'Aurelio Ranzato

Vincent et al. **Extracting and composing robust features with denoising autoencoders.** *ICML* (2008)

Recurrent Neural Nets

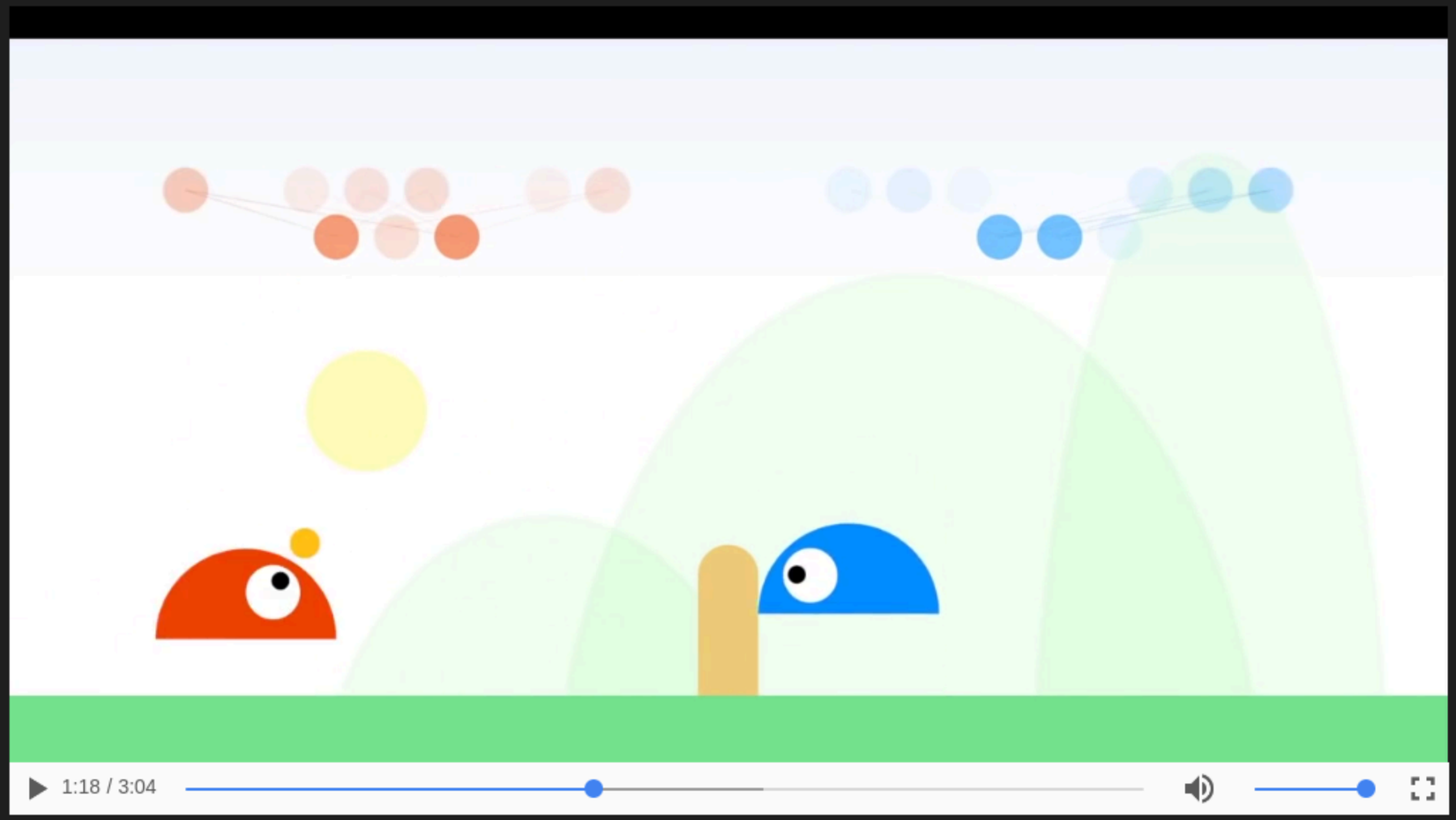


Recurrent Neural Nets



Recurrent Neural Nets

Playing Volleyball :)

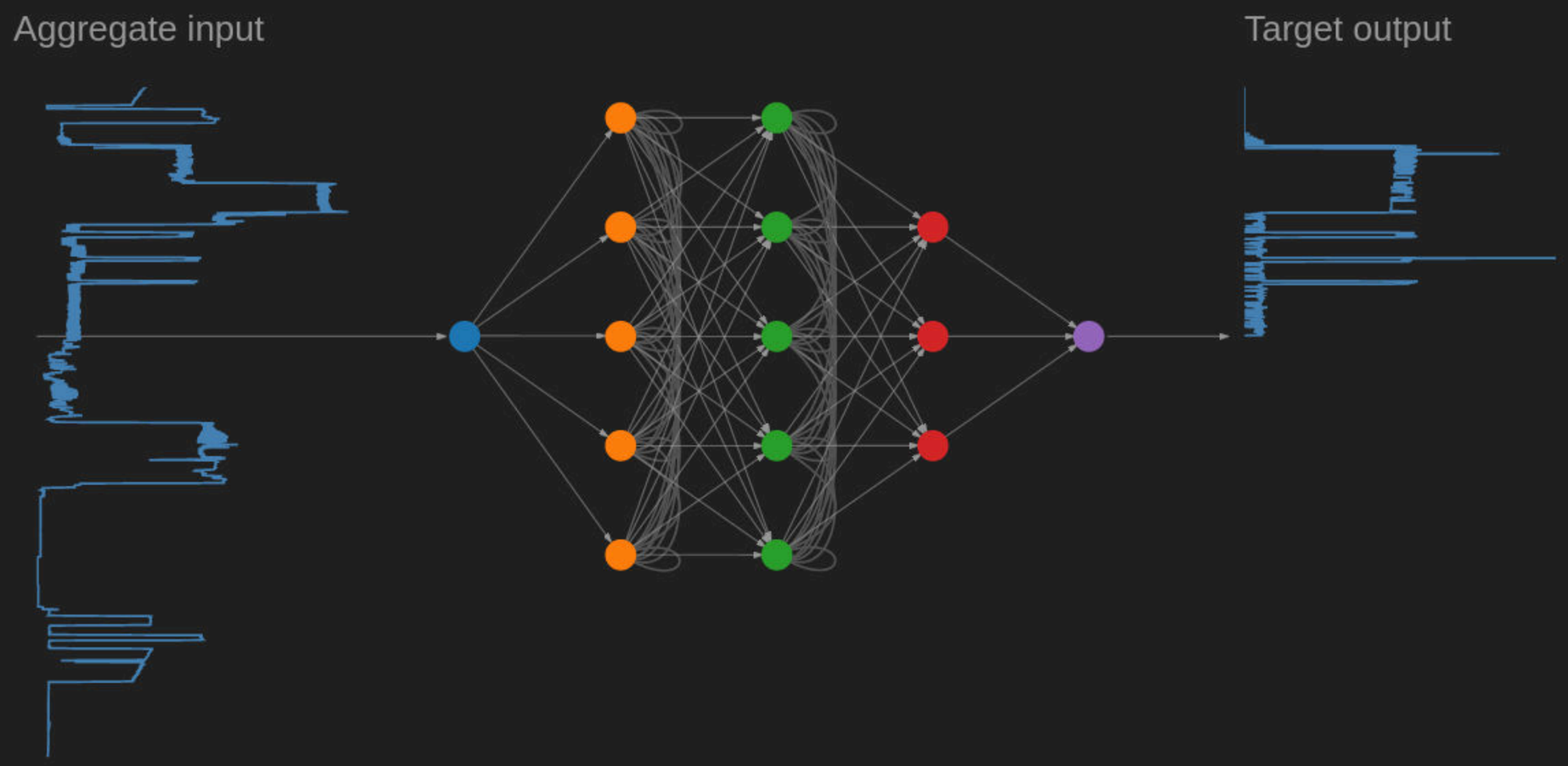


By hardmaru / ōtoro / 大トロ

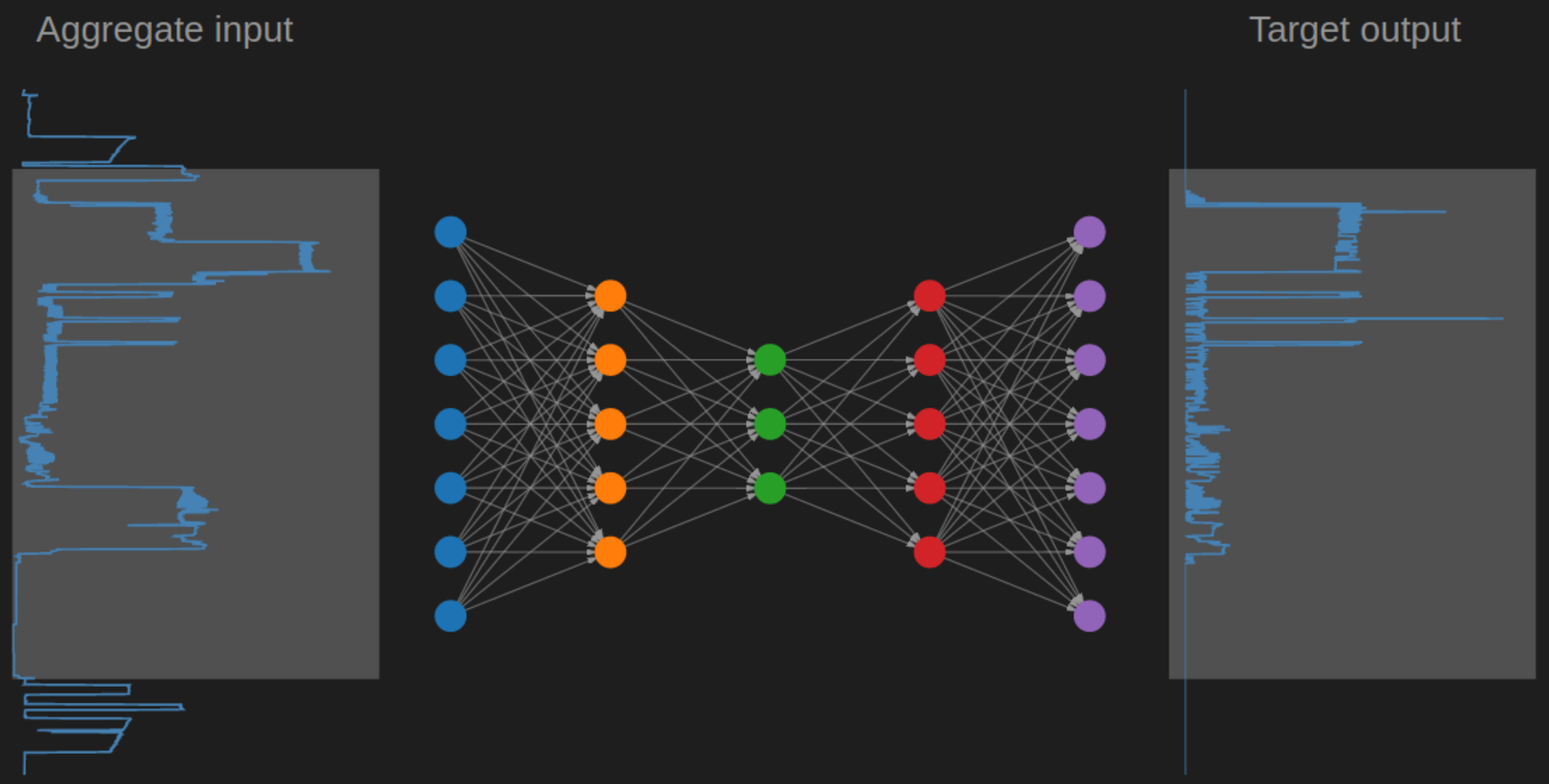
Outline

1. Why use deep neural nets (DNNs) for NILM?
2. How DNNs work
3. Three DNN architectures for NILM
    1. Recurrent Neural Nets (LSTM)
    2. Denoising Autoencoder
    3. 'Bounding rectangle' around the target
4. Data augmentation
5. Results
6. Summary

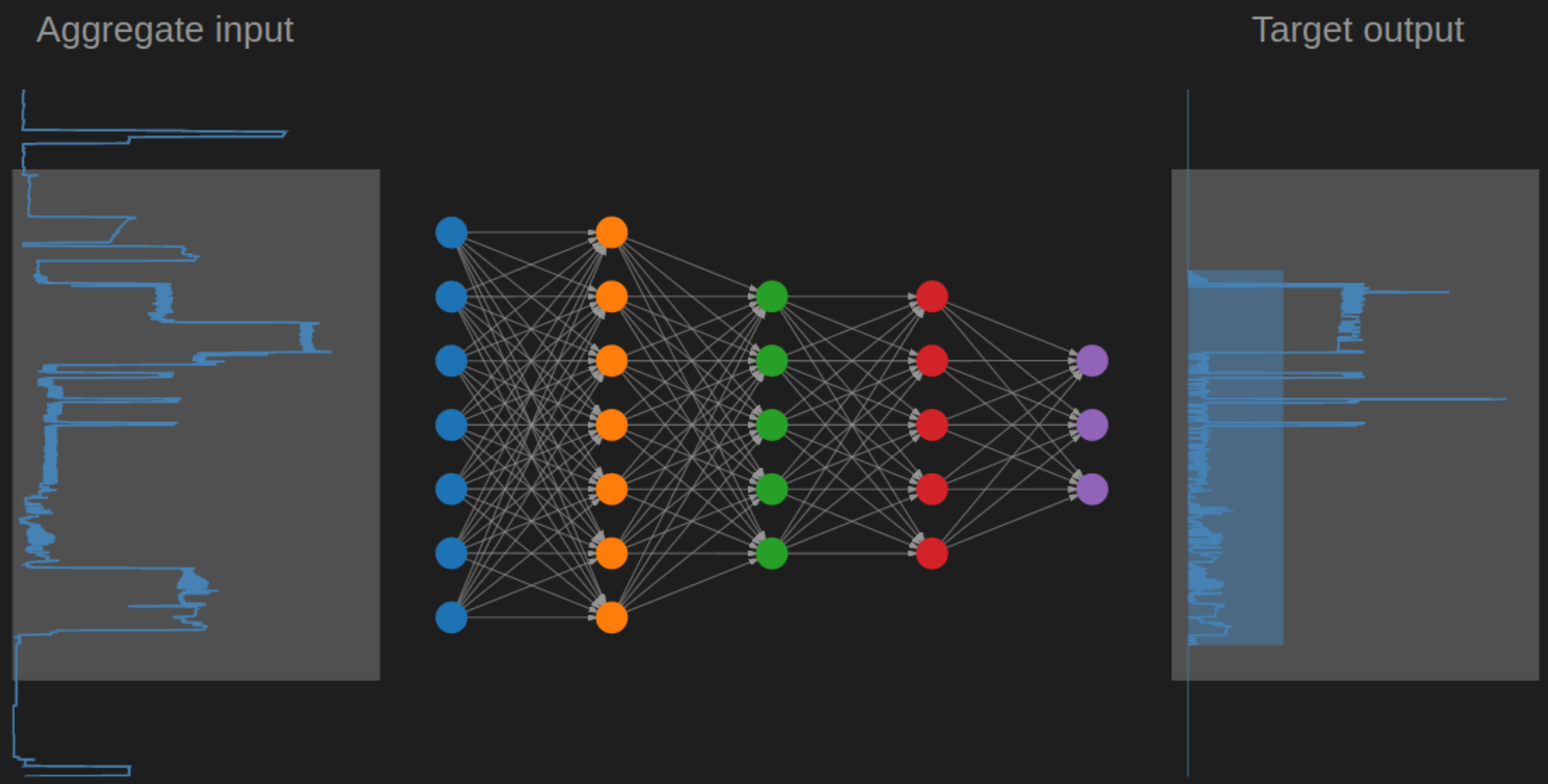
Recurrent Neural Nets



Denoising Autoencoders



Bounding Rectangle



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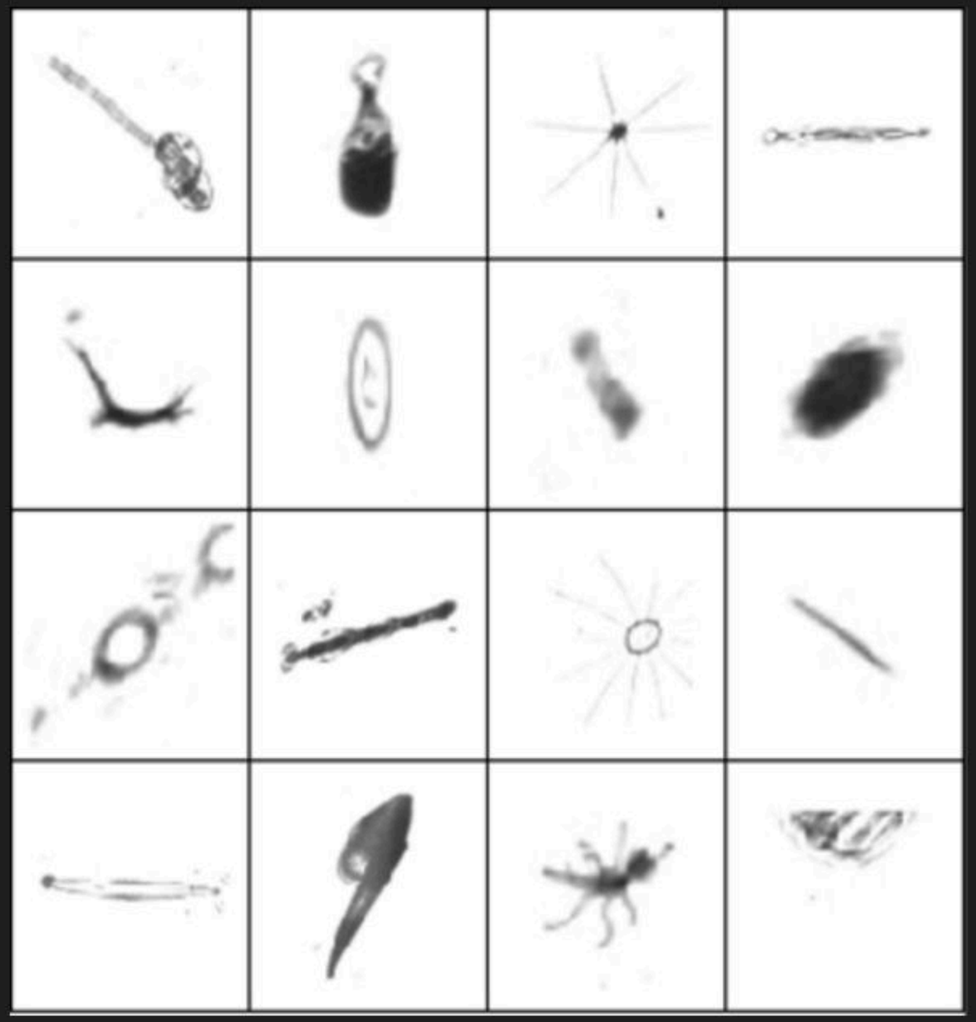
DNNs need lots of data!

Data Augmentation for Images of Plakton

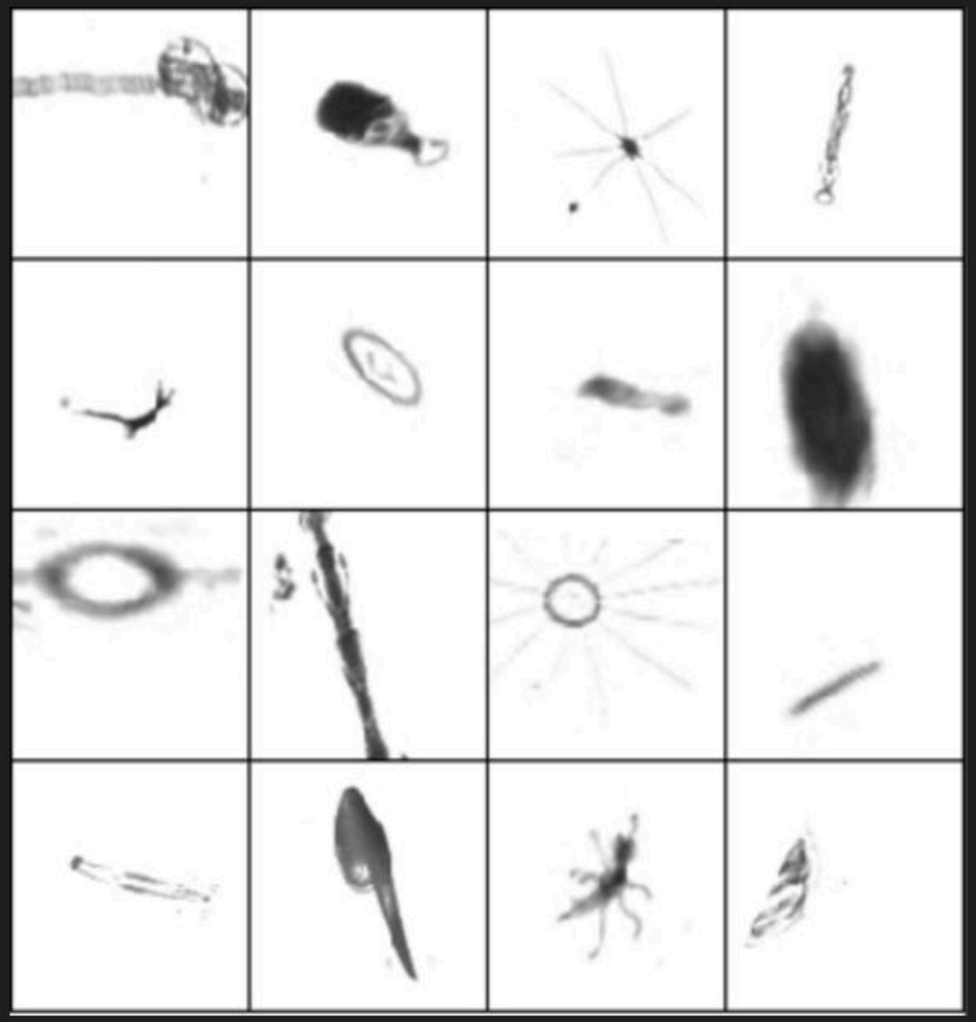
Raw



From ≋ Deep Sea ≋ team (Dieleman et al.) on Kaggle National Data Science Bowl Plankton competition

Data Augmentation for Images of Plakton

Augmented



From ≋ Deep Sea ≋ team (Dieleman et al.) on Kaggle National Data Science Bowl Plankton competition

Data Augmentation for NILM

Data Augmentation for NILM

- Extract individual appliance activations from real data
- For each generated example:
  - Randomly pick which appliances to include
  - Randomly pick individual activations
  - Randomly align activations

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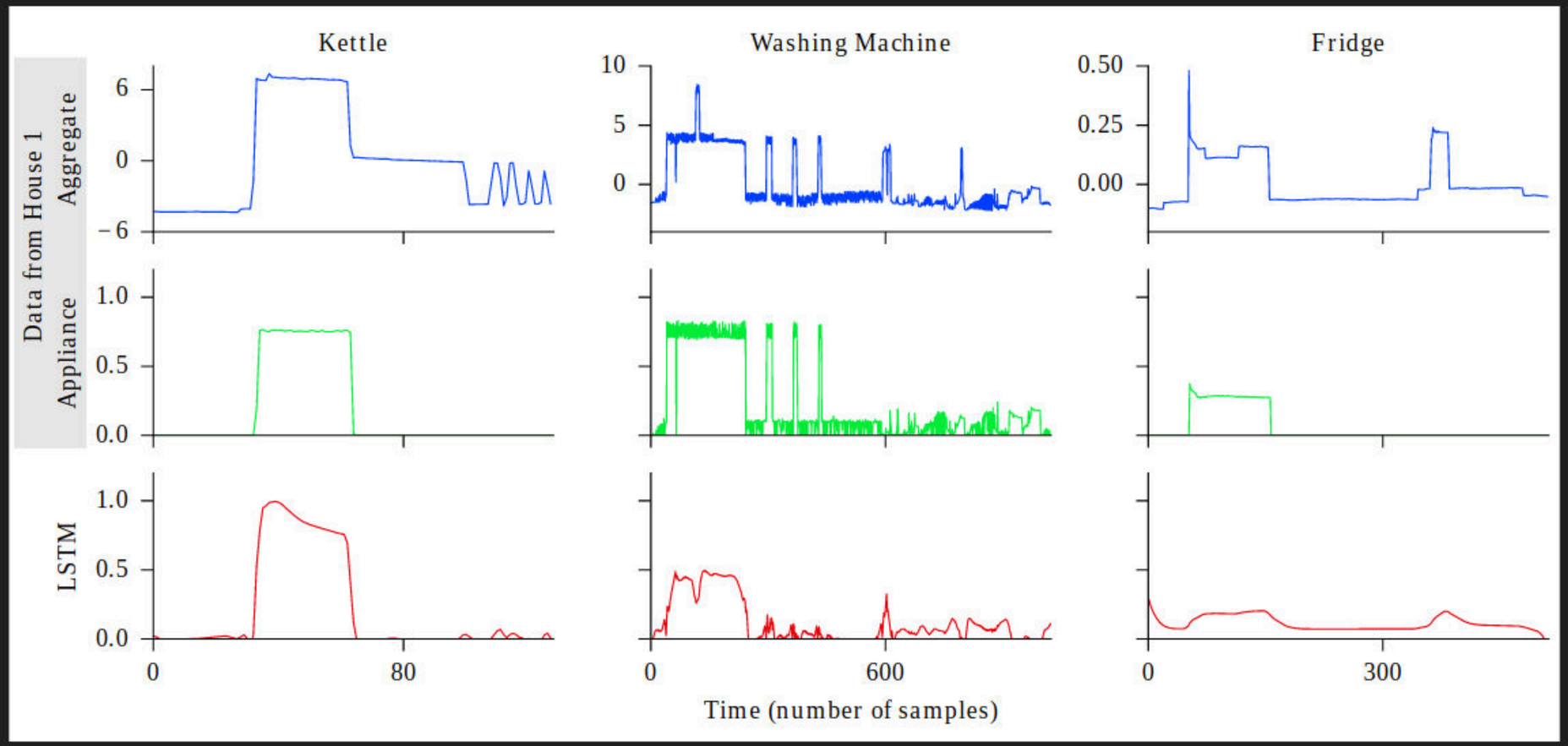
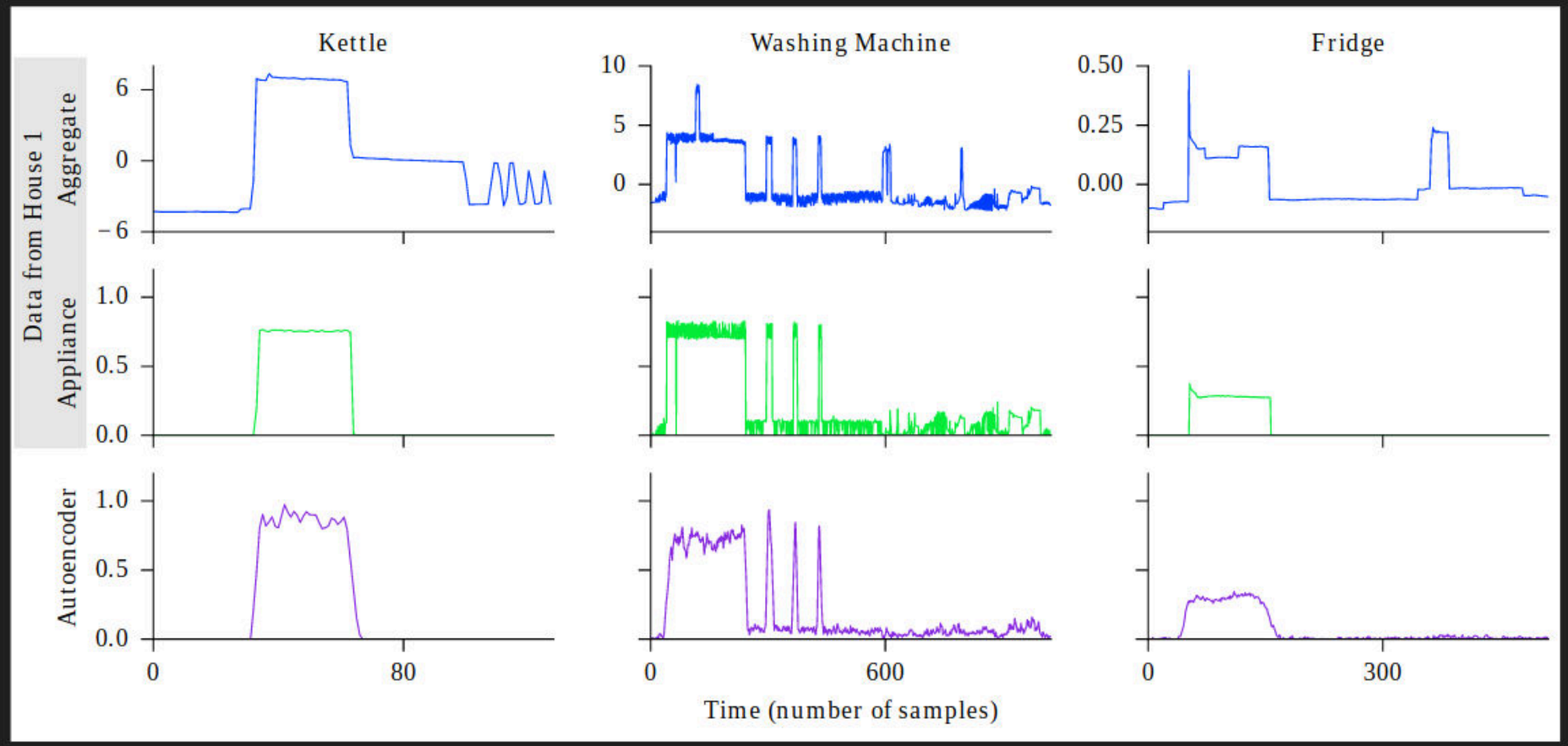
Example Output

LSTM



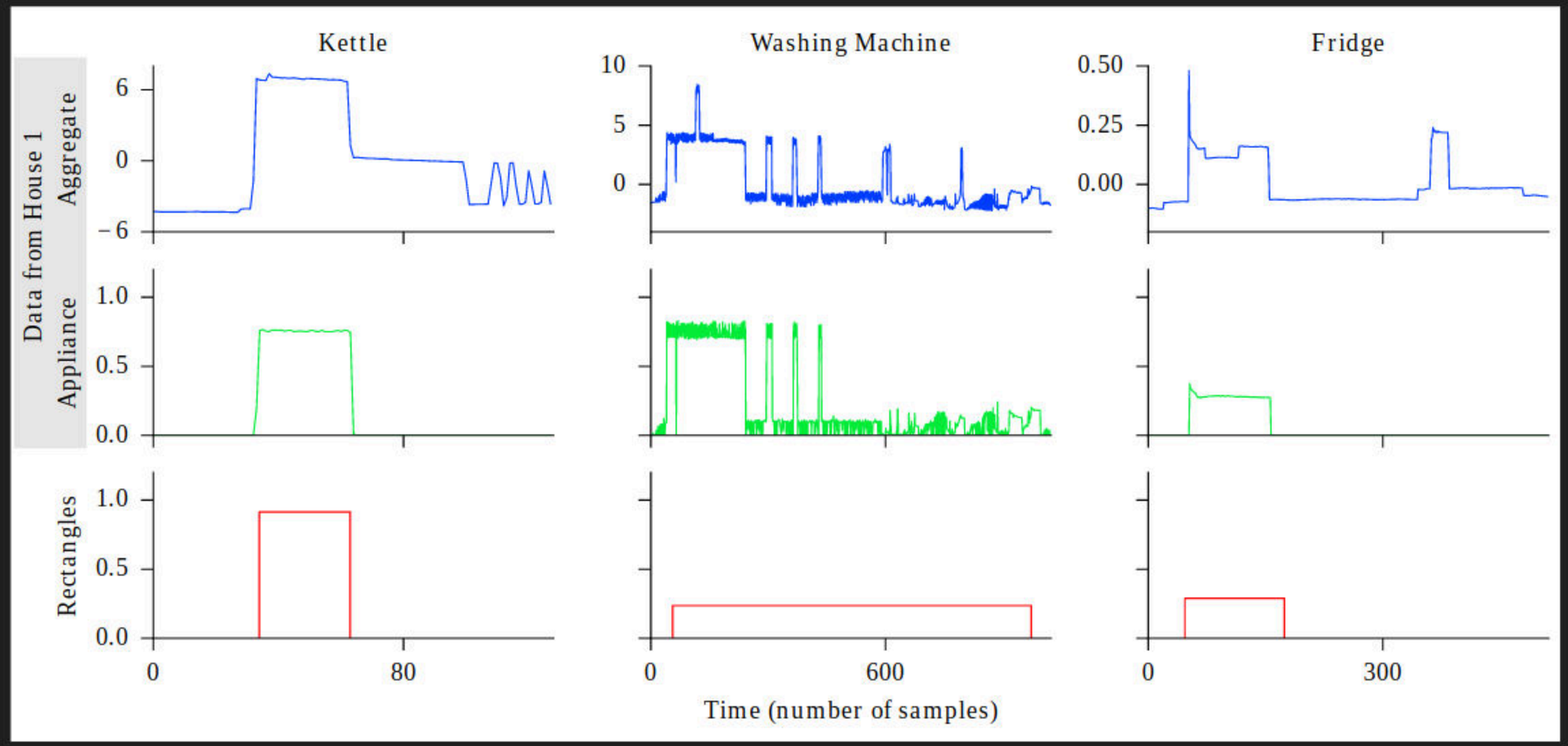
Example Output

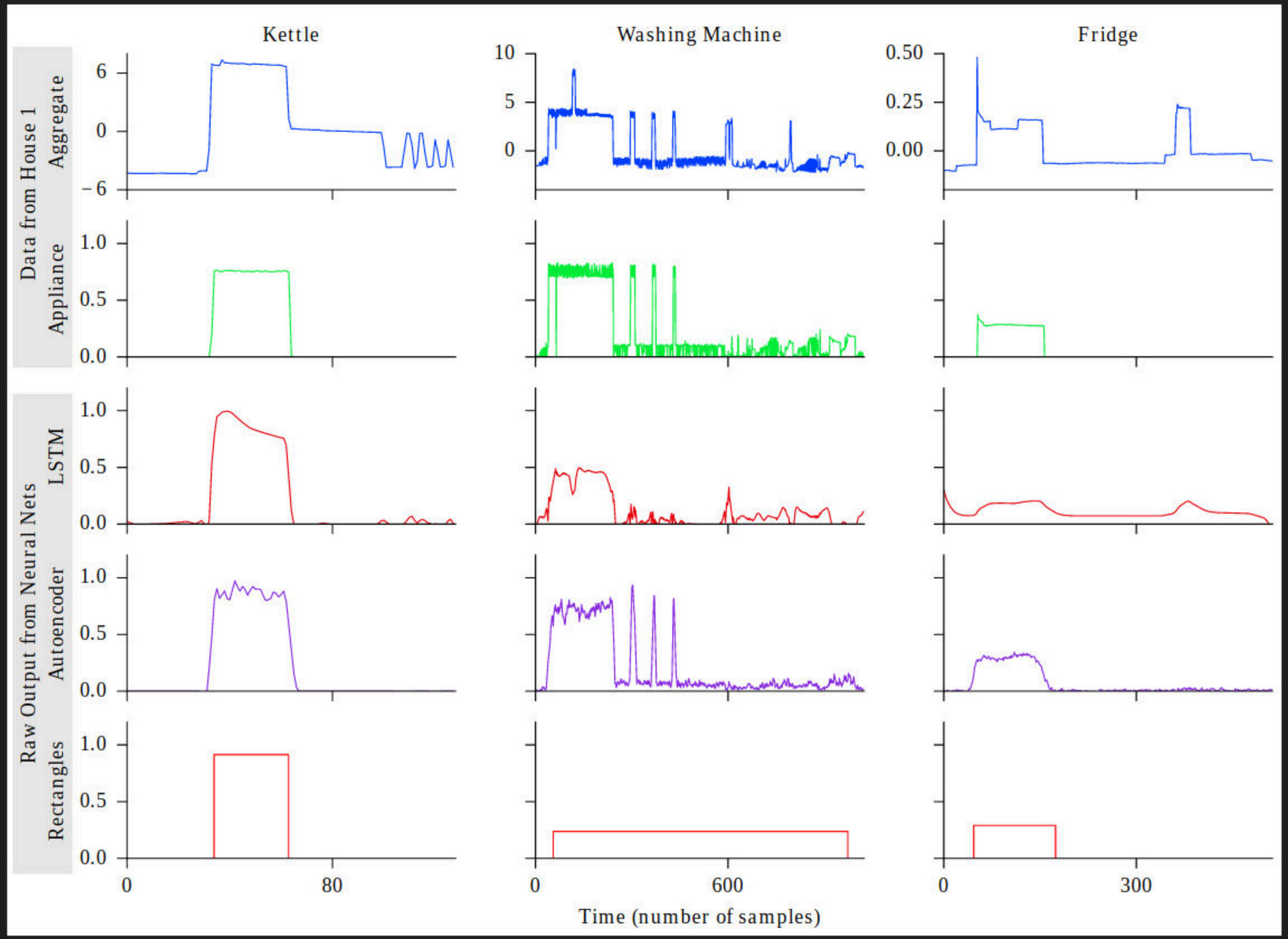
Autoencoder



Example Output

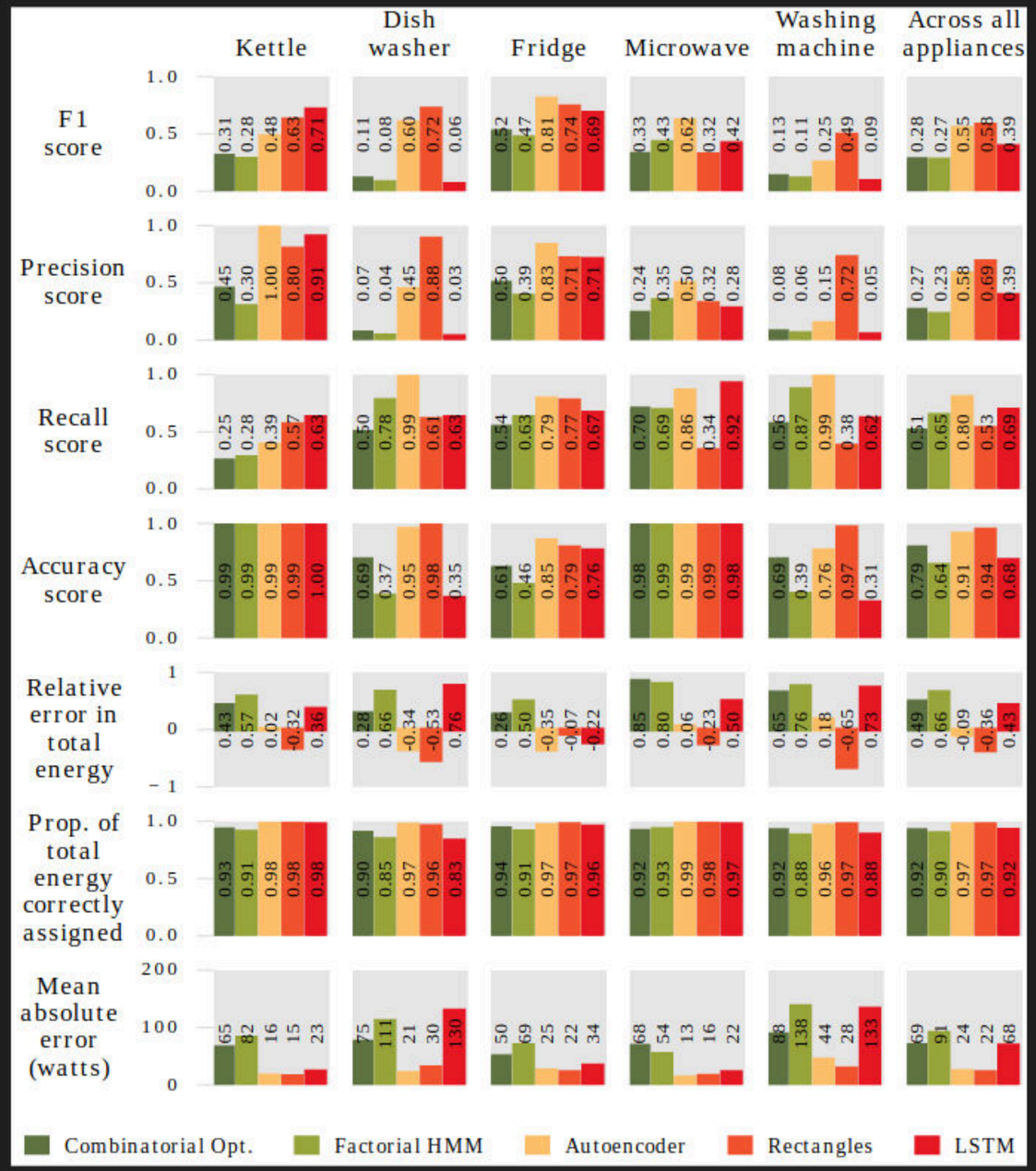
Rectangles



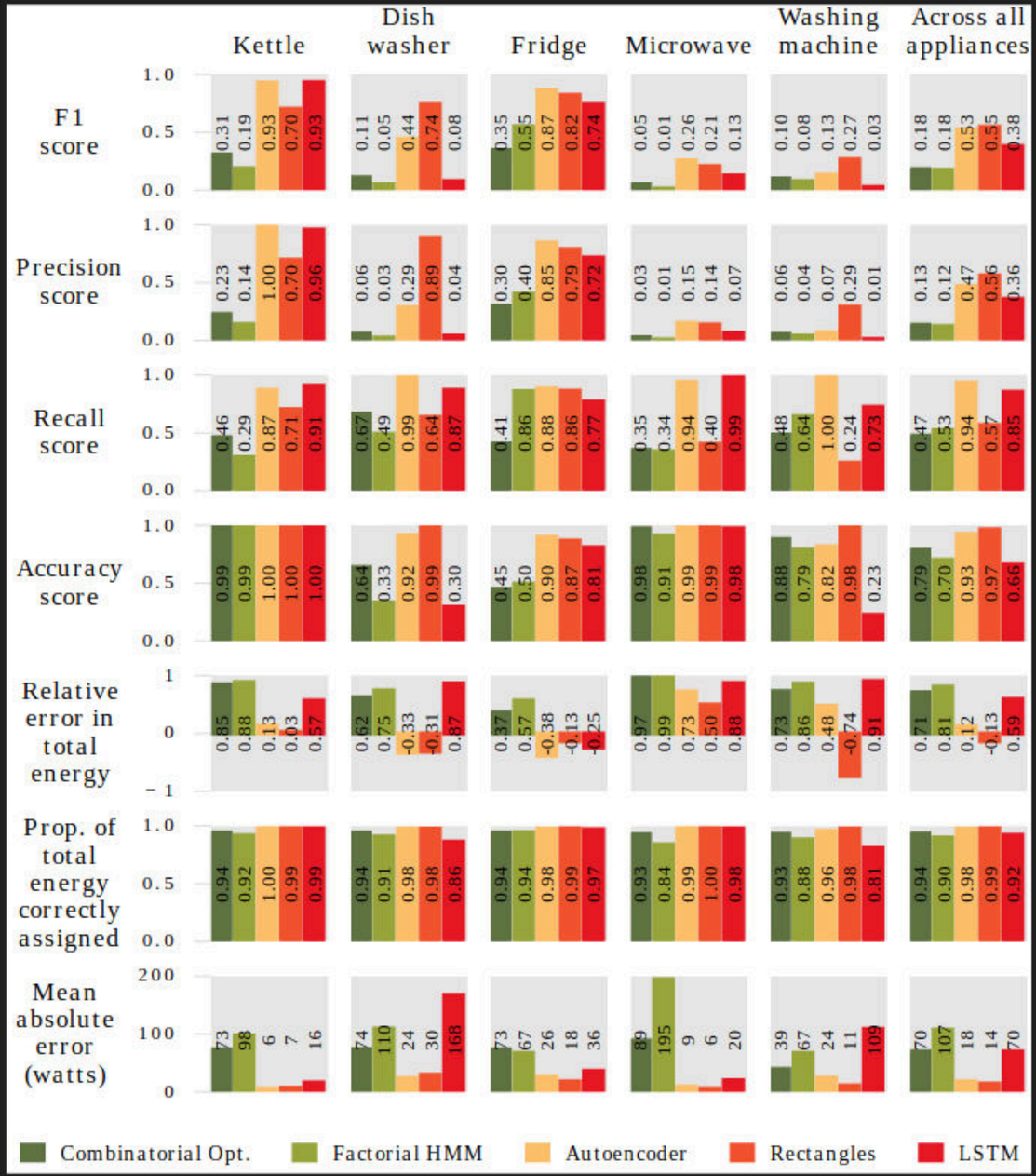

Kettle
Washing Machine
Fridge
Data from House 1
Aggregate
Appliance
Raw Output from Neural Nets
LSTM
Autoencoder
Rectangles
6
0
−6
10
5
0
0.50
0.25
0.00
1.0
0.5
0.0
0
80
600
300
Time (number of samples)

Metrics

Metrics on Seen Appliances



Metrics on Unseen Appliances



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Summary

1. Developed 3 deep neural nets for NILM
2. They perform better than NILMTK's CO or FHMM algorithms (on UK-DALE)
3. Code and Data available:
    1. www.doc.ic.ac.uk/~dk3810/neuralnilm
    2. github.com/JackKelly/neuralnilm
4. Just scratched the surface!
5. Several companies have developed commercial NILM services using deep neural nets (e.g. Onzo)