Capsule Network with Routing Mechanism

Part 2: Matrix Capsule & EM Routing

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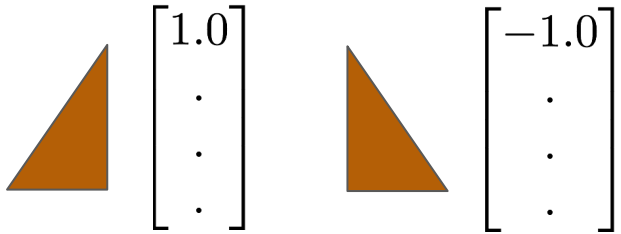
Agenda

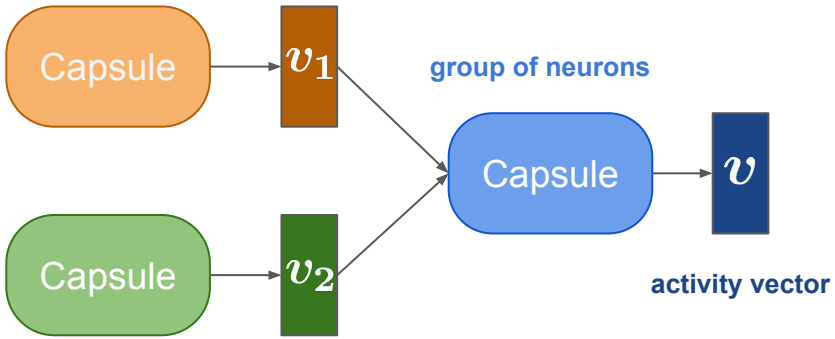
1. **Recap & Matrix Capsule Network**
   - (Vector) Capsules
   - Dynamic Routing by Agreement
   - (Recap: Capsule blueprint & Routing by Agreement
   - Matrix) Capsules Blueprint
2. **Routing Mechanism and Unsupervised Clustering**
   - *Dynamic Routing & k-Mean*
   - *GMM & EM Routing* & Gaussian Mixture Model
3. **Experiments**
   - smallNORB classification task
   - Adversarial examples

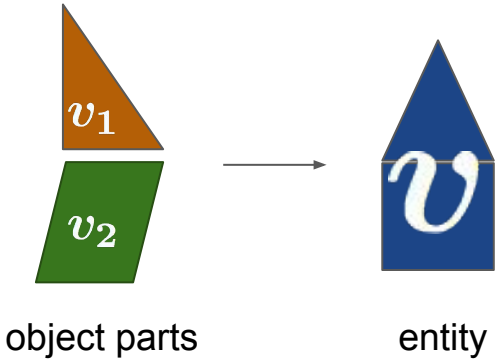
(Vector)**Capsules** blueprint

- *"A **capsule** is **a group of neurons** whose **output represents** different properties of **the same entity**."*

- General ideas differ from [Sabour et al. 2017]:
  - Vector → Matrix
  - Activity Vector → Pose Matrix + Activity Probability







[Hinton, G. E., Sabour, S., Frosst, N. (2018). **Matrix Capsules with EM Routing.**]

Dynamic *Routing* (*by Agreement*)

Routing Algorithm

Initialize $b_{11}, b_{21} = 0$

***for** r **in** range(1...T)*

$$c_{1r}, c_{2r} = \text{softmax}(b_{1r}, b_{2r})$$

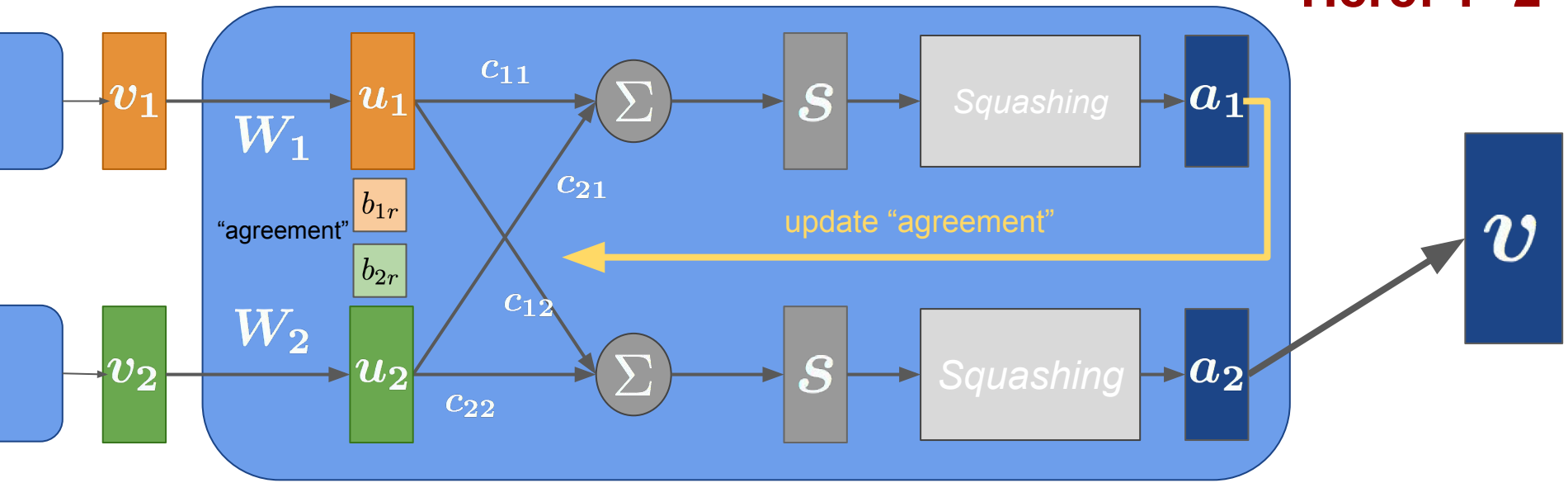
$$a_r = squashing(c_{1r}u_1 + c_{2r}u_2)$$

$$b_{1(r+1)} = b_{1r} + a_r \cdot u_1$$

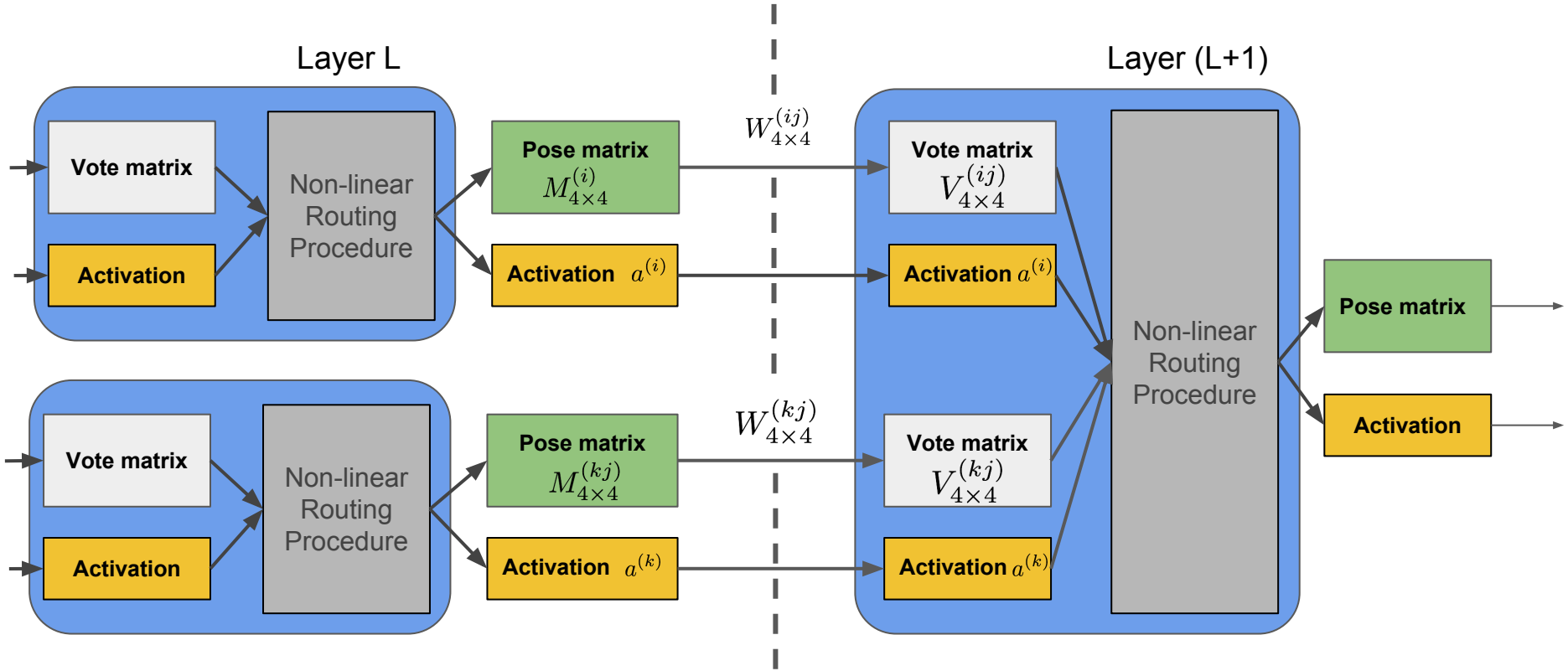
$$b_{2(r+1)} = b_{2r} + a_r \cdot u_2$$

$\|v\|$ is confidence

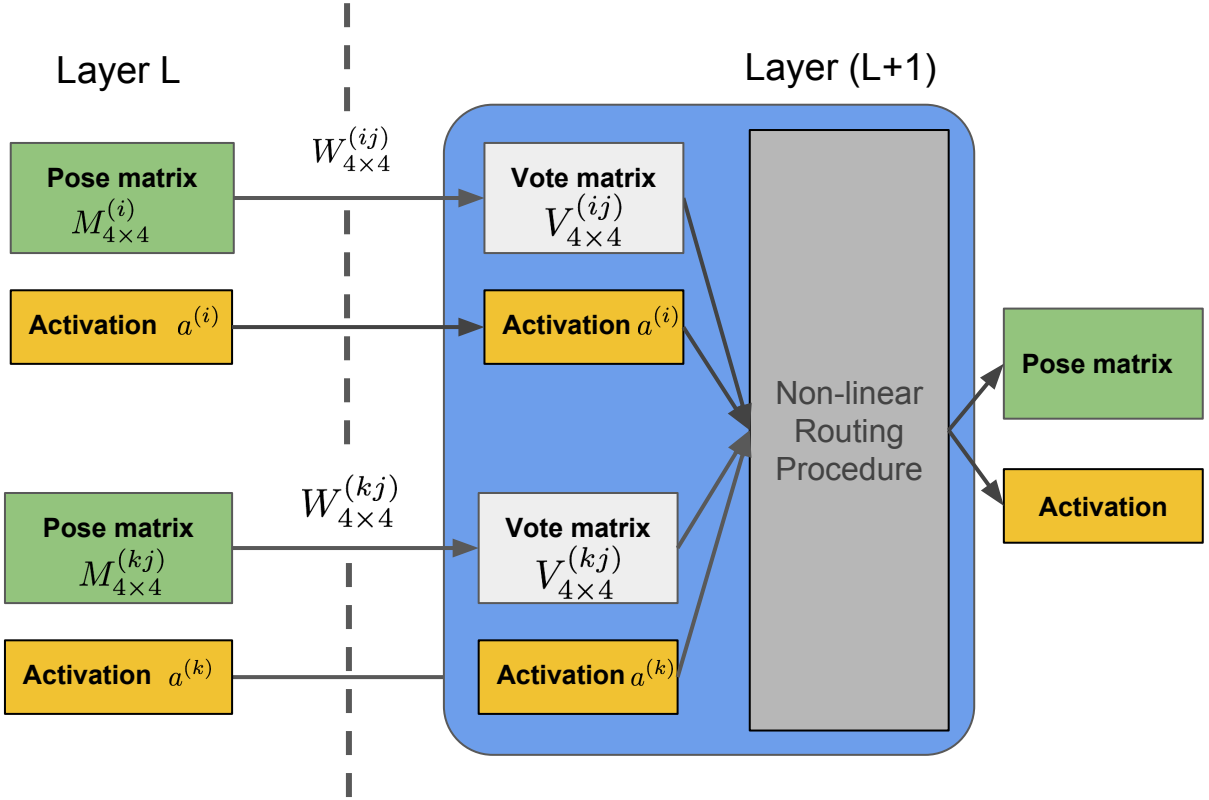
Here: T=2



(Matrix) Capsule Network Blueprint



Routing by EM Clustering (GMM)



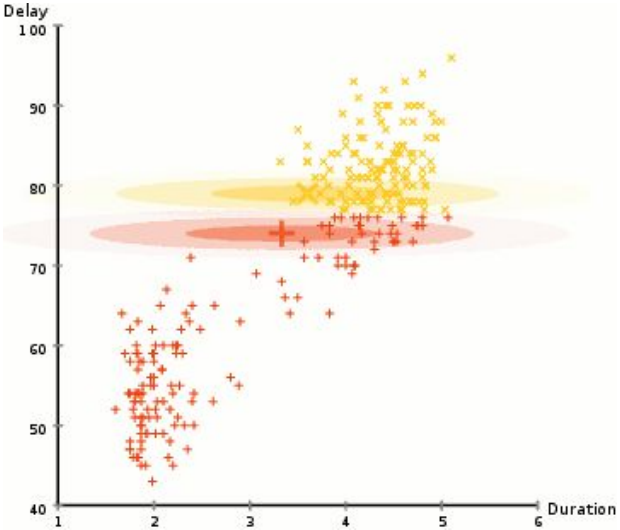
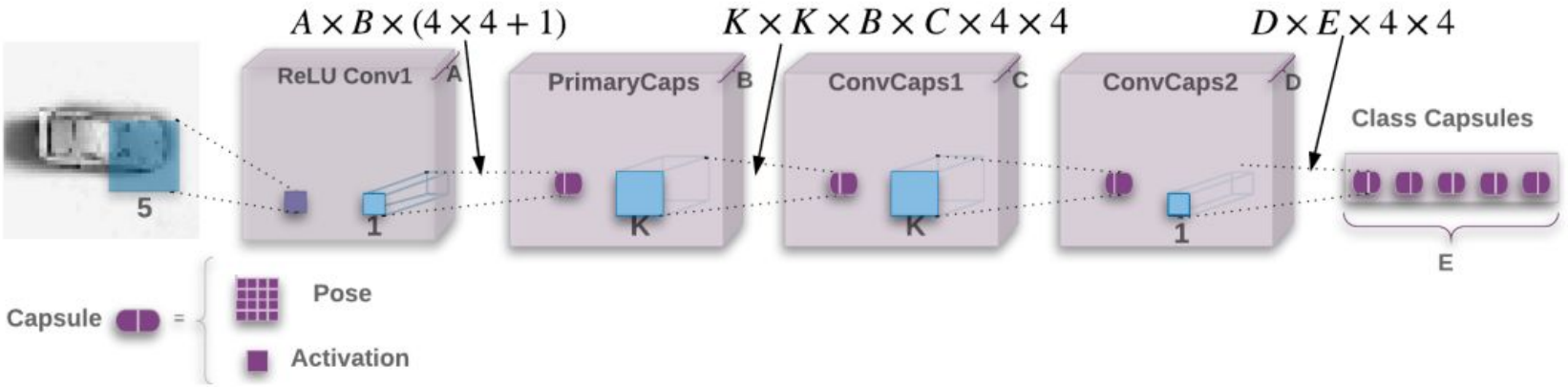
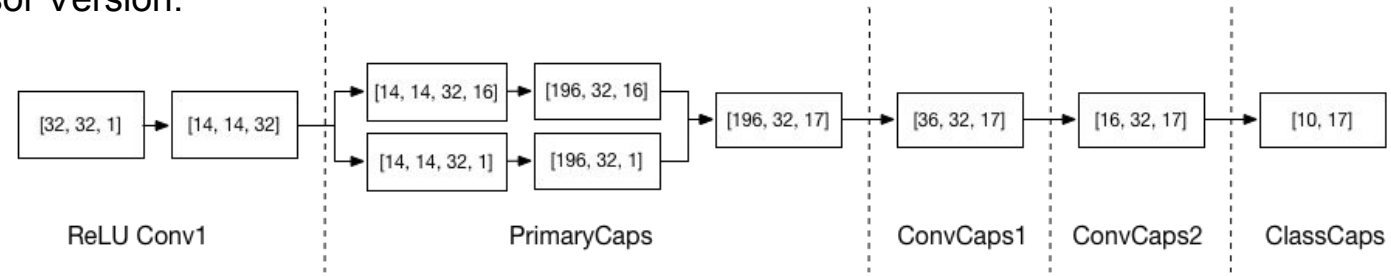


Image source from wikipedia “EM Algorithm”

Architecture: Matrix Capsule



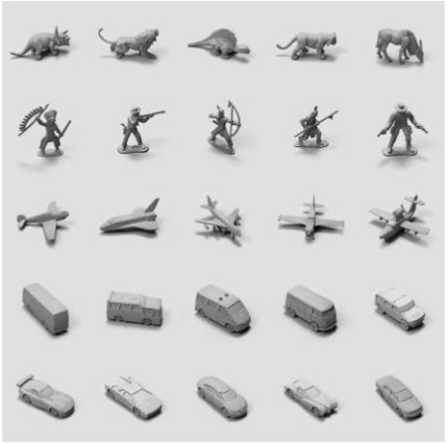
Tensor Version:



[Hinton, G. E., Sabour, S., Frosst, N. (2018). **Matrix Capsules with EM Routing.** ICLR 2018]

Experiments: smallNORB

Routing iterations	Pose structure	Loss	Coordinate Addition	Test error rate
1	Matrix	Spread	Yes	9.7%
2	Matrix	Spread	Yes	2.2%
3	Matrix	Spread	Yes	**1.8%**
5	Matrix	Spread	Yes	3.9%
3	Vector	Spread	Yes	2.9%
3	Matrix	Spread	No	2.6%
3	Vector	Spread	No	3.2%
3	Matrix	Margin[1]	Yes	3.2%
3	Matrix	CrossEnt	Yes	5.8%
Baseline CNN with 4.2M parameters				5.2%
CNN of Cireşan et al. (2011) with extra input images & deformations				2.56%
Our Best model (third row), with multiple crops during testing				**1.4%**



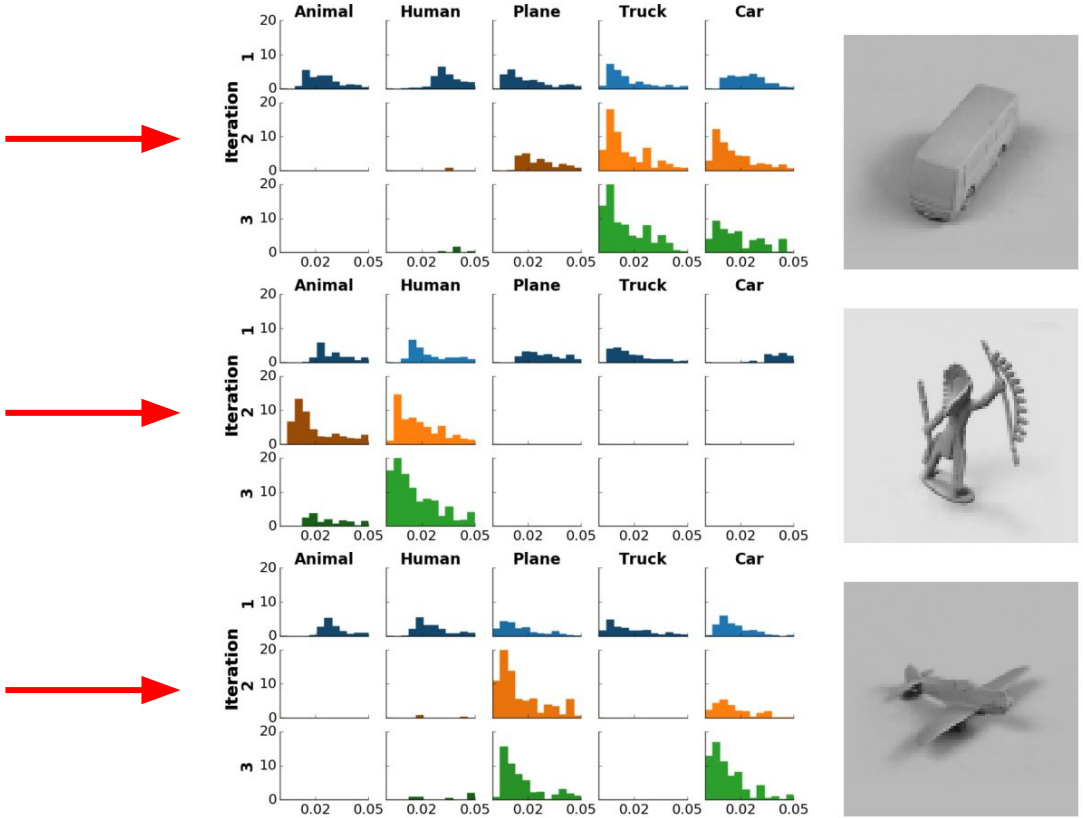
https://cs.nyu.edu/~ylclab/data/norb-v1.0-small/

Open Source Implementation:

- CNN baseline (4.2M): 88.7%(best)/94.8%(paper)
- Matrix Cap with EM routing (310K, 2 iteration): 91.8%(best)/98.6%(paper)
- https://github.com/www0wwwjs1/Matrix-Capsules-EM-Tensorflow

[Hinton, G. E., Sabour, S., Frosst, N. (2018). **Matrix Capsules with EM Routing.** ICLR 2018]

Experiments: smallNORB



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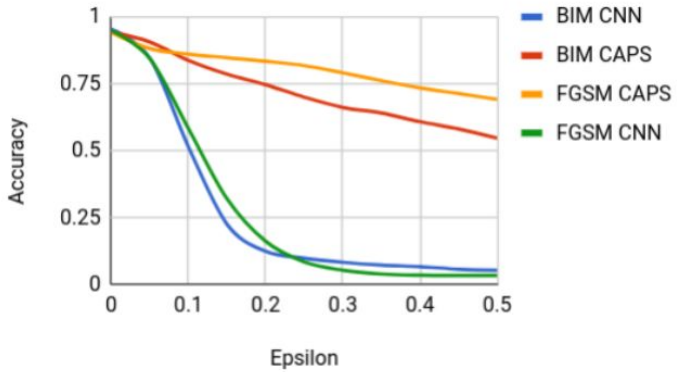
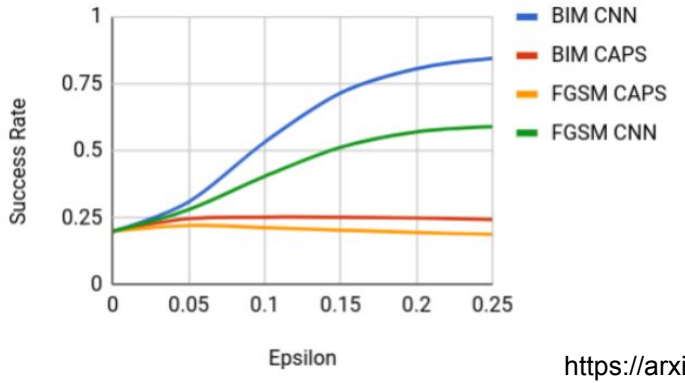
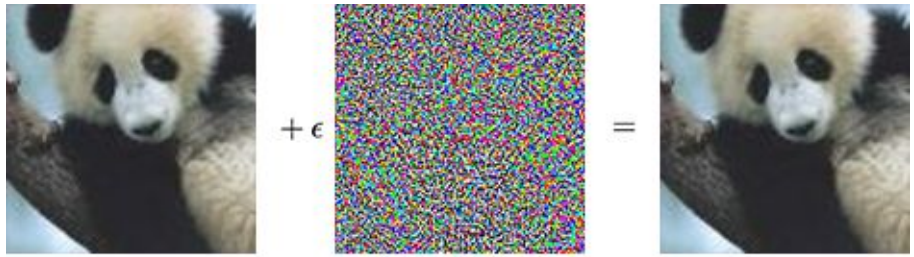
Experiments: Adversarial Robustness





https://arxiv.org/abs/1412.6572

*BIM & FGSM are methods for creating adversarial examples



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Summary of Matrix CapsNet

- Key Points of Matrix Capsule:
  - **(Matrix, Activation) → (Matrix, Activation)**
  - **Encapsulate** entity or its **pattern**
  - **Routing** by *agreement* Mechanism
  - ...
- Pros:
  - Equivariance
  - Built-in interpretability
  - Adversarial robustness
- Cons:
  - Reproducibility
  - Computational Performance
  - Routing process
  - ...

References of this Section

1. [Hinton, G. E., Krizhevsky, A., & Wang, S. D. (2011, June). **Transforming autoencoders**. In International Conference on Artificial Neural Networks (pp. 44-51). Springer, Berlin, Heidelberg.]
2. [Su, J., Vargas, D. V., & Kouichi, S. (2017). One pixel attack for fooling deep neural networks. *arXiv:1710.08864*.]
3. [Hinton, G (2017). **What's wrong with convolutional neural nets**. *https://www.youtube.com/watch?v=Mqt8fs6ZbHk&t=562s*]
4. [Sabour, S., Frosst, N., & Hinton, G. E. (2017). **Dynamic Routing Between Capsules**. *arXiv:1710.09829*.]
5. [Hinton, G. E., Sabour, S., Frosst, N. (2018). **Matrix Capsules with EM Routing.** ICLR 2018]
6. [Sukhbaatar, S., Weston, J., & Fergus, R. (2015). End-to-end memory networks. In Advances in neural information processing systems (pp. 2440-2448).]
7. [Hung-Yi Lee (2017). Capsule. *https://www.youtube.com/watch?v=UhGWH3hb3Hk*]