# **Equivariant Neural Tangent Kernels**

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Can be used to study

We provide

**Group pooling** to enforce invariance



• Influence of data augmentation

## **Recursive relations** for equivariant layers

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We provide relations for group convolutional neural network (GCNN) layers

Group convolution Group pooling **Non-linearity** 

This allows us to compute the equivariant kernels layer-by-layer



tools to study the training dynamics of (infinitely) wide equivariant neural networks



## **Experiments**

Work in progress

Implemented in the jax package **neural**tangents<sup>3</sup> for roto-translations in the plane

### **Convergence test**

- Checking convergence to analytical results for NTK and NNGP via Monte Carlo estimation
- Group  $G = C_4 \ltimes \mathbb{R}^2$



### Example: group convolutional layer

$$egin{aligned} &K_{g,g'}^{(\ell+1)}(f,f') = rac{1}{ ext{vol}(S_\kappa)} \int_{S_\kappa} & ext{d} h \; K_{gh,g'h}^{(\ell)}(f,f') \ & \Theta_{g,g'}^{(\ell+1)}(f,f') = K_{g,g'}^{(\ell+1)}(f,f') \ & +rac{1}{ ext{vol}(S_\kappa)} \int_{S_\kappa} & ext{d} h \; \Theta_{gh,g'h}^{(\ell)}(f,f') \end{aligned}$$

### References

<sup>1</sup>: Jacot et al, Gabriel, F. & Hongler, C. Neural Tangent Kernel: Convergence and Generalization in Neural Networks. in Advances in Neural Information Processing Systems vol. **31** (Curran Associates, Inc., 2018). <sup>2</sup>: Cohen, T. & Welling, M. Group Equivariant Convolutional Networks. in Proceedings of The 33rd International Conference on Machine Learning 2990–2999 (PMLR, 2016). <sup>3</sup>: Novak, R. et al. Neural Tangents: Fast and Easy Infinite Neural Networks in Python. in Eighth International Conference on Learning Representations (2020).

### Histological image classification

• Human colorectal cancer (CRC) and normal tissue in 9 classes • Using the NTK as a kernel method

 $\mu(x) = \Theta(x,\mathcal{X})\Theta(\mathcal{X},\mathcal{X})^{-1}\mathcal{Y}$ 





**Read more** 



