# Learning Responses

## Applications of SIREN

Brett Viren

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# Basics of usual field response / induced current calculation

## Step 1: Solve Laplace equation with two sets of boundary conditions

$$\nabla^2 \Phi(\mathbf{r}) = 0 \quad \text{in } \Omega, \qquad \Phi(\mathbf{r}) = g(\mathbf{r}) \quad \text{on } \partial\Omega.$$

drift $\Phi_d$ potential with boundary electrodes at applied voltages.

weighting $\Phi_{w,k}$ a single electrode $k$ at 1V, all others are 0V.

## Step 2: Combine by stepping through **drift** and applying Shockley-Ramo

$$I_k(t_i) = q\, \mathbf{v}_d \cdot \mathbf{E}_{w,k}, \qquad \mathbf{v}_d = \mu \mathbf{E}_d = -\mu \nabla \Phi_d, \qquad \mathbf{E}_{w,k} = -\nabla \Phi_{w,k}.$$

## Step 3: Tabulate paths starting at grid of *impact positions* $\{x_j\}$ at *response plane*

Discrete array in transverse location vs drift step: $I_{ij}$.
Typically sampled at 100ns over 10cm (wires) or 20cm (strips) across 0+/-10 wire/strip regions.

# LArTPC field response calculators / Laplace solvers

GARFIELD **Finite Element Method** (FEM) okay for 2D wire model. FORTRAN, arcane config, single-threaded, slow. Garfield++ is a C++ rewrite (see drifiers)

pochoir **Finite Difference Method** (FDM) okay for hybrid 2D+3D strips+holes or pixels. Modern Python with GPU acceleration but computation speed and result correctness still needs optimizing.

larf **Boundary Element Method** (BEM) in principle can solve bigger problems (eg, 3D, larger domain) but hasn't been explored since initial work.

These all have some shared limitations:

- Computational resources require hours to days of CPU or GPU.
- Results tabulated as discrete steps along pre-defined paths.
  - Nice match to the FFT-based simulation and signal processing.
  - Fail to sample certain important transitions and subject to falling into saddle points.

New (to me) 4th method: a learned solution.

# Learning Laplace

The basic idea is:

- Pick some artificial neural network architecture.
- Form a *loss function* in terms of Laplace's equation and boundary comparisions.
- Turn the crank to train.

This approach **learns physics** directly.

- Not a *surrogate model*, there is no training set produced by some simulation.

But, there are some caveats.