Lecture 9

Last time: basic CNN arch.

higher level concepts
Beyond basic CNN

1. 2015: Inception Block (Google)
   - won ImageNet 2014
   - added diff. filter sizes in each layer

2. 2015: ResNet (Microsoft)
   - CNNs prevented from going very deep (100 layers)
   - ble of vanishing gradients

ImageNet competition / database
- 1M images, color, higher res.
- 1000 categories
Idea: allow CNN skip layers

```
\[ \text{F}(x) \xrightarrow{\text{layers}} \text{F}(x) + x \]
```

"skip connection"
"residual layer"

Dep. on input \( x \), NN could decide \( F(x) < 0 \) (skip)
or not.

Allowed training networks \( \sqrt{\text{even 1000's of layers!}} \)

Major breakthrough in perf., still close to SOTA.

\( \text{let time NN surpassed } \) "human perf." on ImageNet.
- CNNs are optimized for images → powerful part. joins
  - demonstrates power of specialized architectures, leverage structure & symmetry of specific dataset.

- other datasets have other special architectures
  - natural language processing: text → meaning (time series) or sequences.
  - speech recognition: voice → text

\[ \text{RNNs, LSTMs, GRUs, Transformers & Attention} \]
Intro to Collider Physics (LHC)

Motivations for non-Higgs people

- Curiosity?
- LHC is ideal playground for ML methods
  - could give ideas for other fields

LHC = Large Hadron Collider

- 27 km circumference

CMS & ATLAS are "jewel purpose" detectors.

Focus on these
LHC is a pp collider
protons are accelerated to 6.5 TeV in energy in opposite directions
units: particle physics energy $eV = \text{energy required to make electron across } 1 \text{ V of potential difference}$
$\varepsilon = mc^2$
energy $\&$ mass same unit
proton mass: GeV
$E = m_0 c^2$
work in natural units $< 1$
$E = \frac{m c^2}{\sqrt{1 - \gamma^2}}$
boost factor $\gamma = \frac{E}{m}$ = 6,500
protons move very fast!
6.5 TeV 6.5 TeV $\rightarrow$ c.o.m. energy 13 TeV

highest energy collider ever "energy frontier"

Beams 2.5 cm 7 cm $\leftrightarrow$

bunches 10 tt protons

2,808 bunches circulating
2.5 ns bunch spacing

$\rightarrow$ 3 x $10^{14}$ protons / beam

36 MJ / beam = KE car (2000 kg) moving at 2000 km / hr!
`proton` → quarks & gluons

**QCD:** quarks & gluons are nearly free "asymptotic freedom":

\[ p \otimes g' \otimes g' \]

carry some fraction \( x \) of proton momentum.

\[
\sigma(pp \to X) = \sum_{a,b=1,2,\ldots} \int dx_1 dx_2 P_a(x_1, Q^2) P_b(x_2, Q^2) \frac{\alpha_s}{\pi} |ab \to X|
\]

cross section

measure of scattering probability

\[
\text{Modgraph, pythia, herwig, }\ldots
\]

\( A, B, C, \ldots \)

\[ \text{computer tools} \]

\[ \text{parton partonic} \]

\[ \text{nonperturbative} \]

\[ \text{extracted from data} \]

\[ \text{perturbative in QCD} \]

\[ \text{and radiatively} \]

\[ \text{correlated to proton level} \]