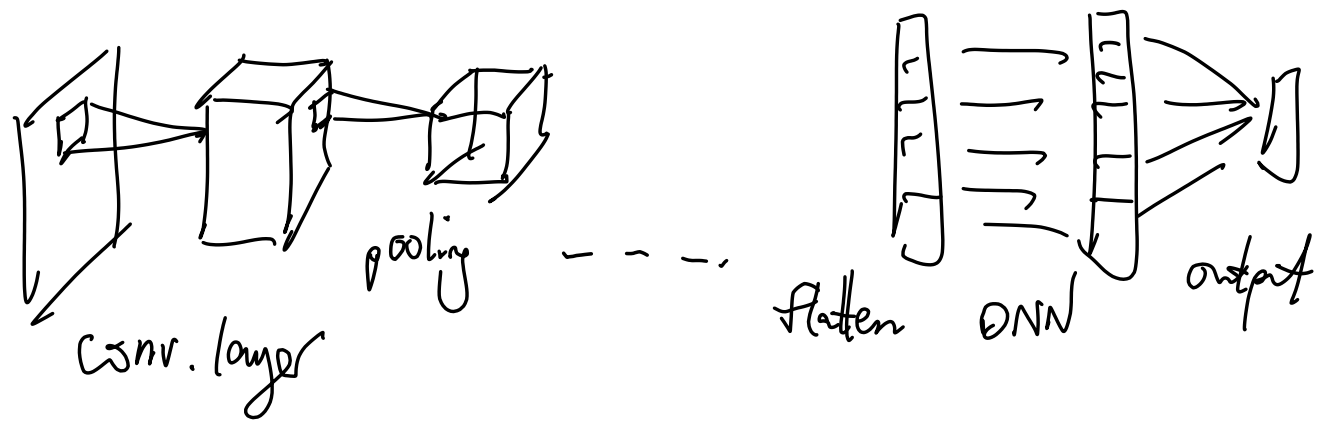


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# Lecture 9

Last time: basic CNN arch.

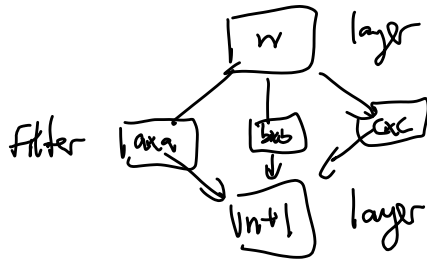


higher level concepts

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## Beyond basic CNN

1. 2015: Inception Block (Google)  
won ImageNet 2014



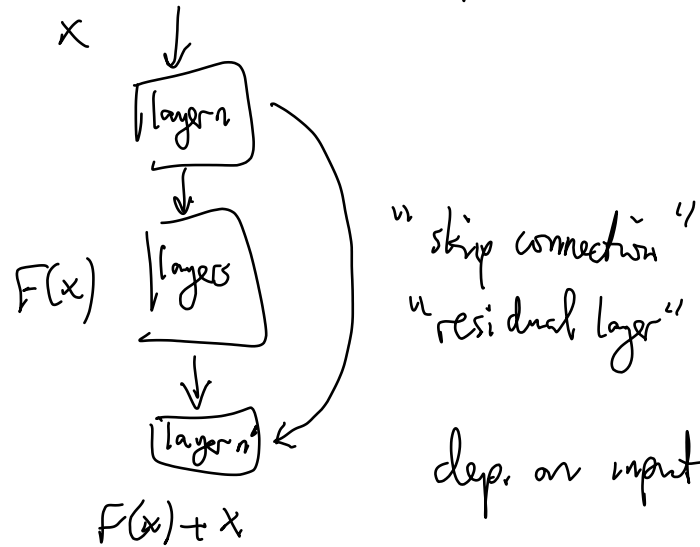
allow diff.  
filter sizes  
in each layer

ImageNet competition / database  
1M images, color, higher res.  
1000 categories

2. 2015: ResNet (Microsoft) : (CNNs prevented from going very deep (100 layers)  
won ImageNet 2015 b/c of vanishing gradients

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Idea: allow CNN skip layers



"skip connection"  
"residual layer"

dep. on input  $x$ , NN could decide  $F(x) \neq 0$  (skipping) or not.

↓  
allowed training networks w/ even 1000's of layers!  
Major breakthrough in perf., still close to SOTA. → let time NN surpassed "human perf." on ImageNet.

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- CNNs are optimized for images  $\rightarrow$  powerful perf. gains
  - demonstrates power of specialized architectures leverage structure & symmetry of specific dataset.

- other datasets have other special architectures

- natural language processing : text  $\rightarrow$  meaning
  - speech recognition : voice  $\rightarrow$  text
- } time series  
or sequences.

$\downarrow$

[ RNNs, LSTMs, GRUs,  
Transformers w/ Attention

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# Intro to Collider Physics (LHC)

Motivations for non-HEP people

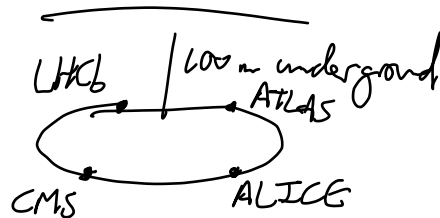
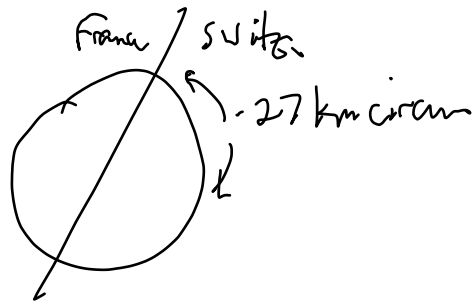
- Curiosity?
- LHC is ideal playground for ML methods

dataset is enormous

simulations are very accurate and relatively inexpensive

↓  
could give ideas for other fields

## LHC Large Hadron Collider



CMS & ATLAS are "general purpose" detectors. focus on these

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LHC is a pp collider

protons are accelerated to 6.5 TeV in energy in opposite directions

hadron collider

e<sup>+</sup>e<sup>-</sup> collider

units: particle physics energy eV = energy required to  
move electron  
across 1V of  
pot'l diff

work in natural units  $c = 1$   
 $\hbar = 1$

$$E = mc^2$$

energy &amp; mass same unit

proton mass: 6eV

$$= 1.6 \times 10^{-19} \text{ J}$$

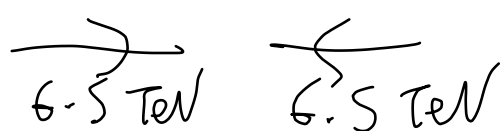
$$\text{TeV} \sim 10^{-7} \text{ J}$$

larger # for &lt; proton

$$\text{boost factor } \gamma = \frac{E}{m} = 6500$$

protons moving very fast!

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 $6.5 \text{ TeV}$      $6.5 \text{ TeV}$

$\rightarrow$  C.M. energy  $13 \text{ TeV}$   
 highest energy collider ever "energy frontier"

Beams  

 $2.5 \text{ ns}$      $30 \text{ cm}$

bunches  $10^{11}$  protons  

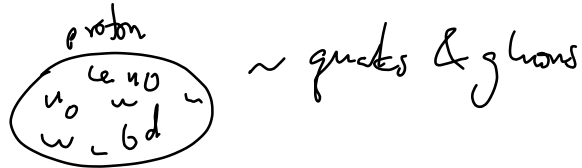
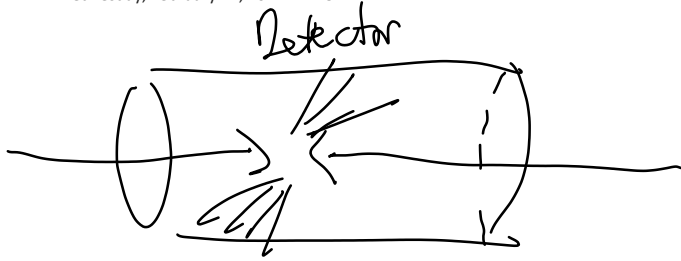
 $10 \text{ mm}$   
 $4$  interaction pts

$2808$  bunches circulating  
 $2.5 \text{ ns}$  bunch spacing

$\rightarrow 3.6 \times 10^{14}$  protons / beam

$36 \text{ MJ / beam} = \text{KE car (2000 kg)}$   
 moving at  $2000 \text{ km per hour!}$

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very high energy

"parton model"



QCD: quarks & gluons are nearly free "asymptotic freedom"  
 carry some fraction  $x$  of proton momentum.  
 momentum transfer "factorization scale"

cross section  
 measure of scattering probability  
 units of area

$$\sigma(pp \rightarrow X) = \sum_{a,b \in u,d,s,\dots,g} \int dx_1 dx_2 P_a(x_1, Q^2) P_b(x_2, Q^2) \hat{\sigma}(ab \rightarrow X)$$

Madgraph, Pythia, Herwig, ...

computer tools

parton dist'n fr. nonpert'ive extracted from data.

hard scattering process parton level compute perturbatively in QCD/...