Machine learning to identify top quarks in stop searches

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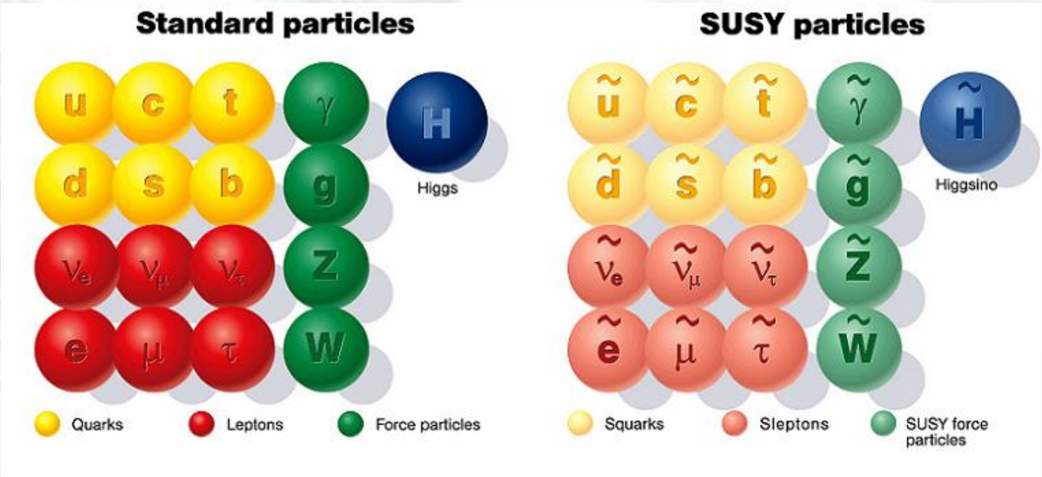
2017 US LHC Users Association Meeting

Introduction

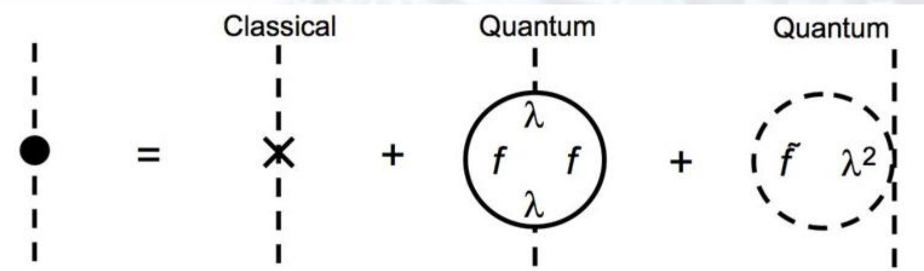


Motivations for Supersymmetry (SUSY) include…

- Hierarchy problem
- Gauge coupling unification
- Dark matter candidate

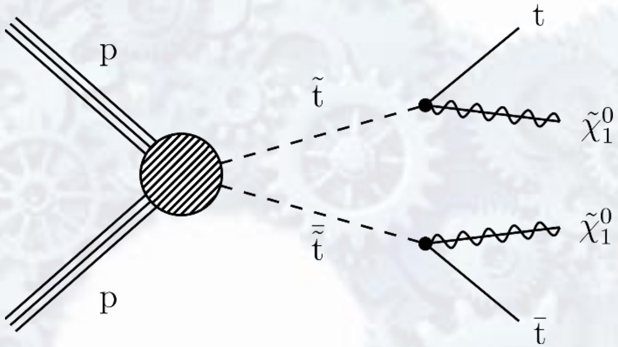
Many super symmetric models predict a stop with a mass near the electroweak scale.

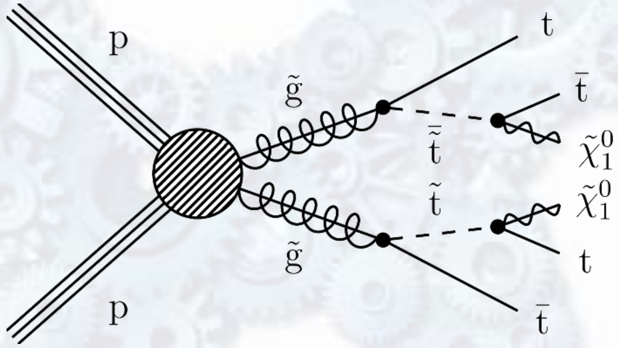
Discovery of the stop could be within the reach of the current LHC. The techniques of machine learning will improve the sensitivity of our searches.



$$m_h^2 = (m_h^2)_0 - \underbrace{\frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2} + \frac{1}{16\pi^2}\lambda^2(m_{\tilde{f}}^2 - m_f^2)\ln(\Lambda/m_h)$$

A multiplicity of tops in the final state





Our search is for the production of stops that decay into an all hadronic final state.

The target models have multiple tops in the final state (2 or 4).

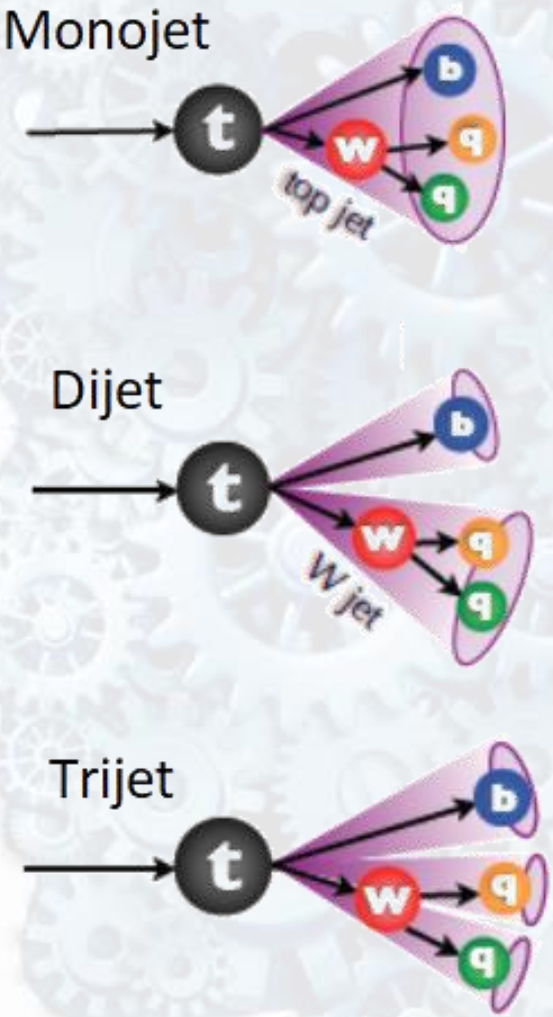
Identifying top quarks and utilizing their kinematics gives us the ability to separate many types of background.

Identified top quarks can be used to form more complex variables.

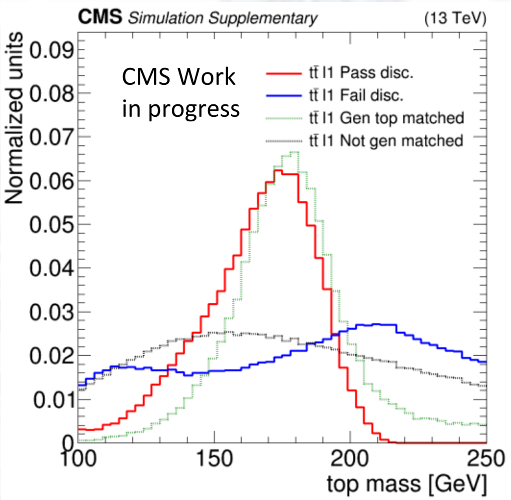
A custom top tagger

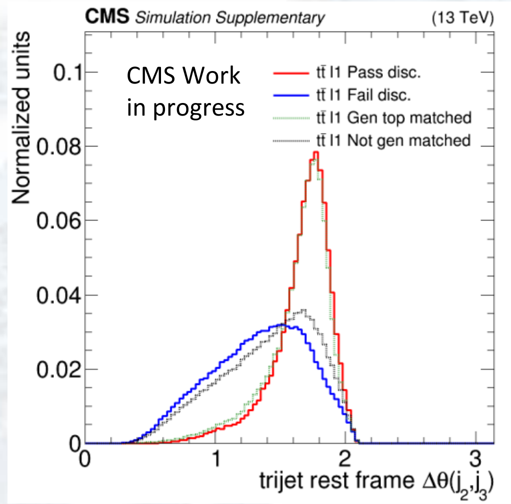
We use a custom tagger that identifies multiple final state tops over a wide p_T range.

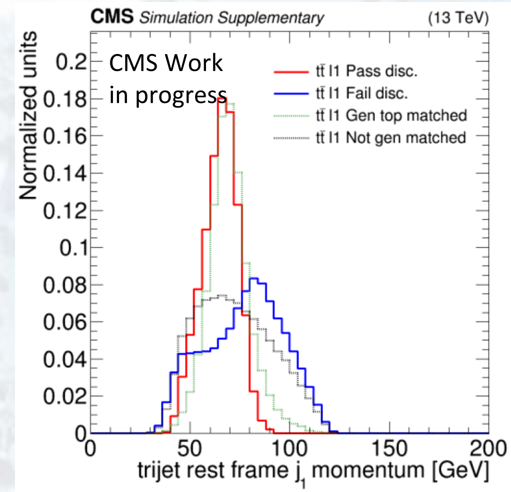
- Monojet top
  - Boosted tops decay into a single wide-cone jet.
  - Identification is based on jet mass and substructure.
- Dijet top
  - Consider combinations of wide-cone jet and nearby narrow-cone jets.
  - The combination must pass mass criteria.
- Trijet top
  - Consider all combinations of narrow-cone jets not previously associated with a mono or dijet top.
  - Each trijet combination is classified by an MVA.
- Before the dijet and trijet tests, jets already associated with a top are removed from consideration.

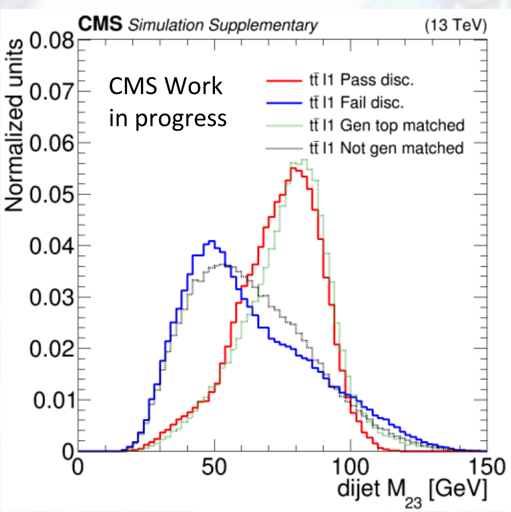


Trijet challenges









Many properties of the trijet system may help identify tops.

Signal and background have distinct distributions; however, no cuts on these variables will provide sufficient identification efficiency and low fake rate.

Why machine learning?

We know how we want to classify the objects

We want to identify a trijet system as a top/not top

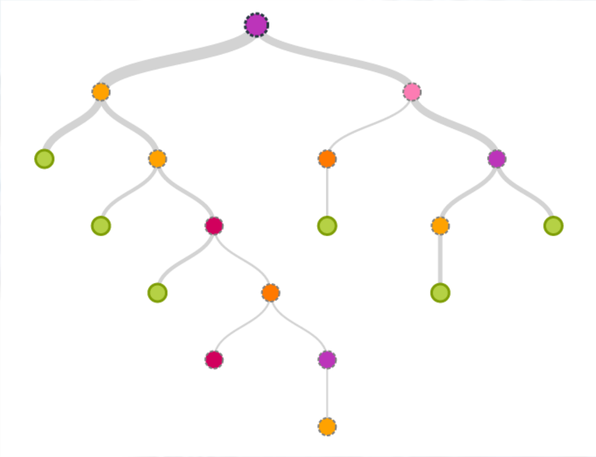
We have data that can help us make the classification

The trijet properties have clearly different distributions, but there is a complicated relationship between the properties and classification.

Machine Learning bridges the gap

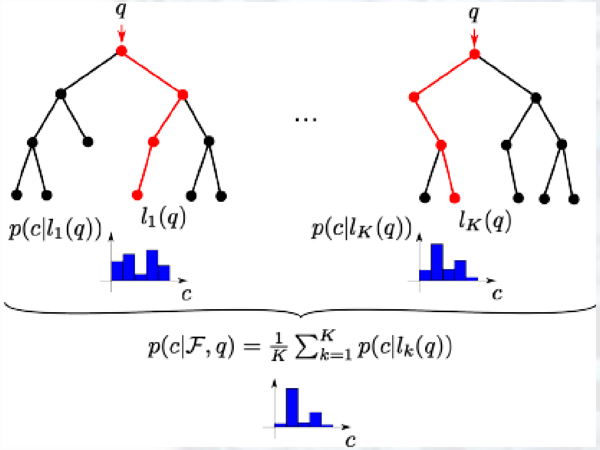
The tagger uses a random forest of decision trees.

A decision tree is a simply connected graph of decision rules.

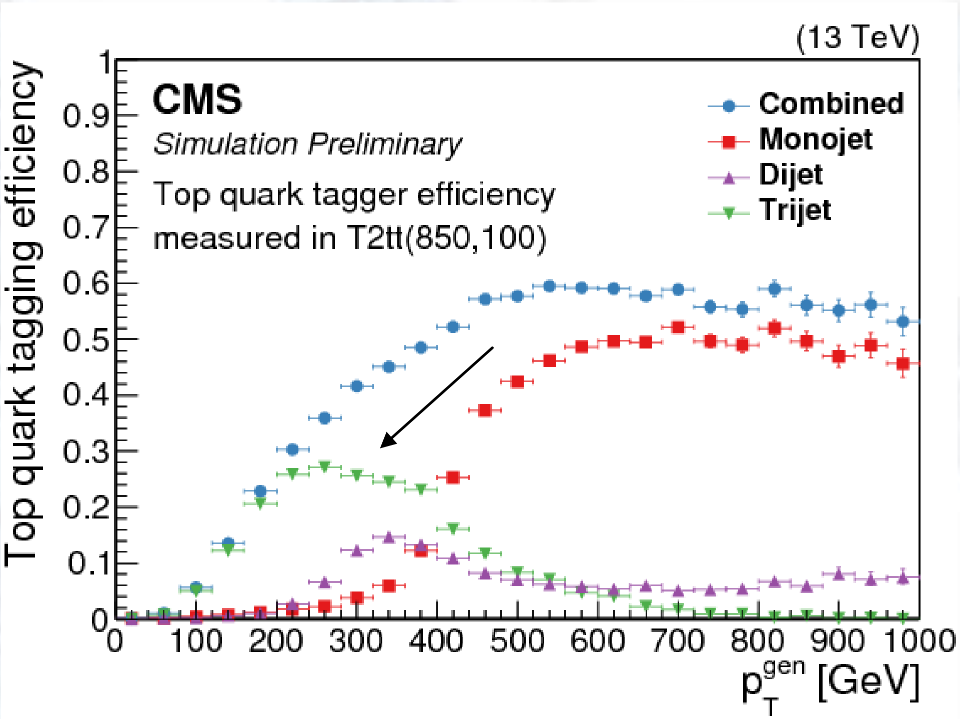


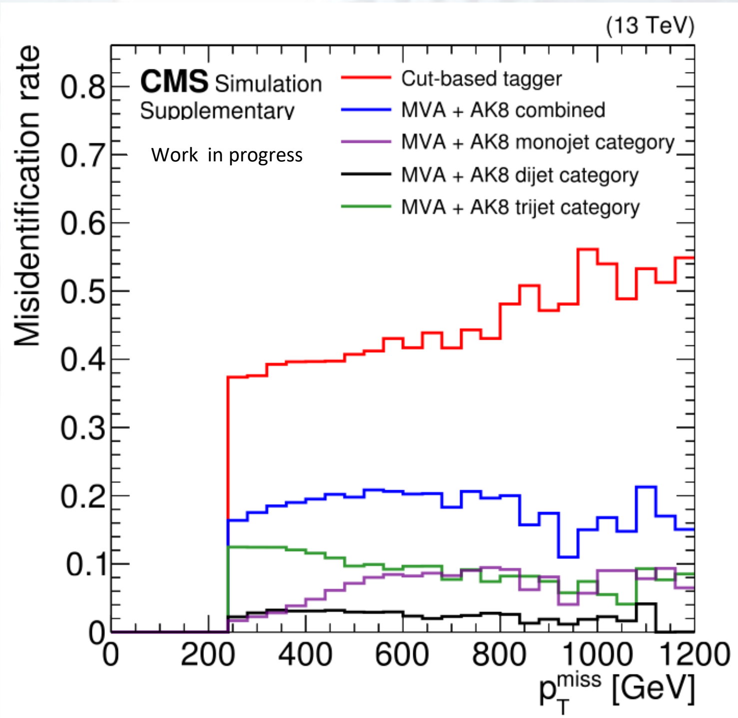
The accuracy of a decision tree can be improved through guided training.

A random forest is an ensemble of decision trees. The outputs are combined to produce a more powerful discriminator capable of handling complicated distributions of classes



Tagger performance

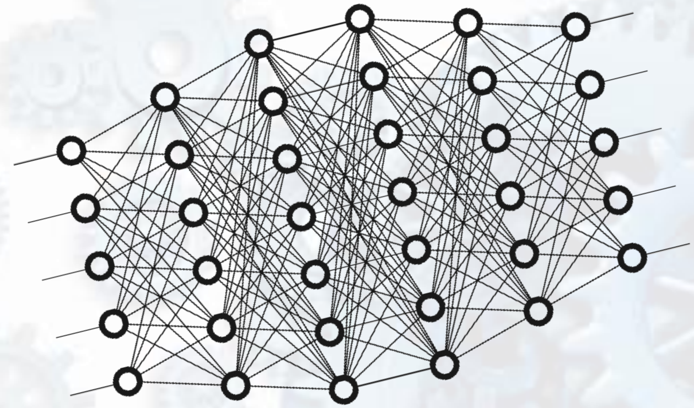




Trijet inclusion is essential to identifying low p_T tops.

The misidentification rate of this tagger is significantly less than the cut-based top tagger used in previous analysis.

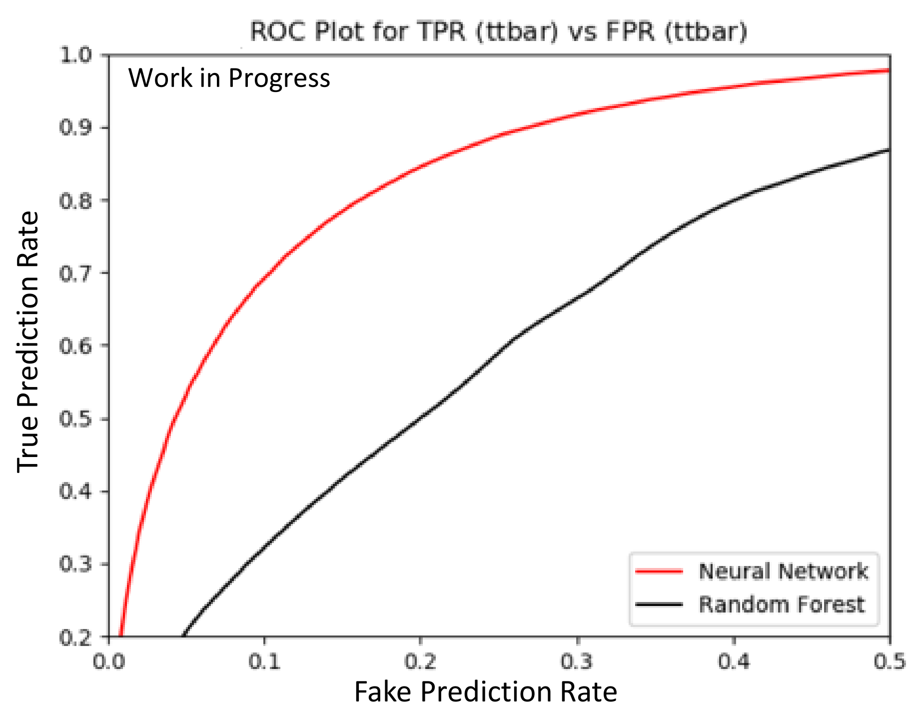
Future: Deep Neural Network



We are developing an even more powerful trijet tagger.

The new tagger is based on a deep neural network.

We already see greater efficiency and lower fake rate.



Summary

- Multiple tops are expected in the final states of the SUSY models studied.
- Machine learning is used to cope with the challenges of identifying low p_T tops.
- Hui Wang will present the results of the search.
- Website: http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-16-050/index.html

Search for supersymmetry using hadronic top quark tagging in 13 TeV pp collisions

The CMS Collaboration

Abstract

A search is presented for supersymmetry in all-hadronic events with missing transverse momentum and tagged top quarks. The data sample was collected with the CMS detector at the LHC and corresponds to an integrated luminosity of 35.9 fb^{-1} of proton-proton collisions at a center-of-mass energy of 13 TeV. Search regions are defined using the multiplicity of bottom and top quark candidates, the presence of an imbalance in transverse momentum, and the hadronic energy in the event. With no statistically significant excess of events observed beyond the expected contributions from the standard model, we set exclusion limits at the 95% confidence level on the masses of new particles in the context of simplified models of direct and gluino-mediated top squark production. For direct top squark production with decays to a top quark and a neutralino, top squark masses up to 1020 GeV and neutralino masses up to 430 GeV are excluded. Gluino masses up to 2040 GeV and neutralino masses up to 1150 GeV are excluded for models of gluino pair production where each gluino decays to a top-antitop quark pair and a neutralino.

Backup

Why Machine Learning?

- We know what results we want. (Classify a trijet combination as a top decay or not).
- We have an intuitive and motivated reasons to suspect that certain inputs can be used to make the classification. (For example the invariant mass of the trijet system, or the value of the b discriminator of the leading pt jet)
- The classified objects have a complicated distribution with the phase space defined by the input variables. (Simple cut based identification performs particularly poorly in the low top pt regime)
- A machine learning method provides an algorithm to make the classification and employs some iterative process to refine and improve the results. (We used a random forest of decision trees)

Image Sources

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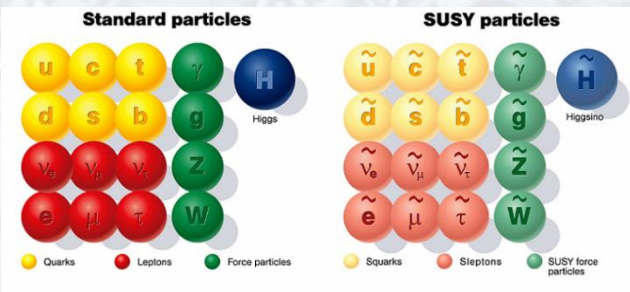

http://www.physics.gla.ac.uk/ppt/images/sus
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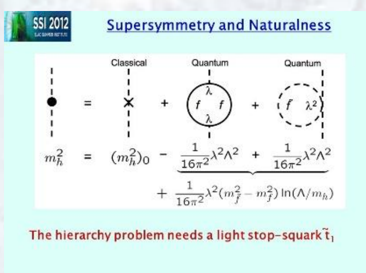

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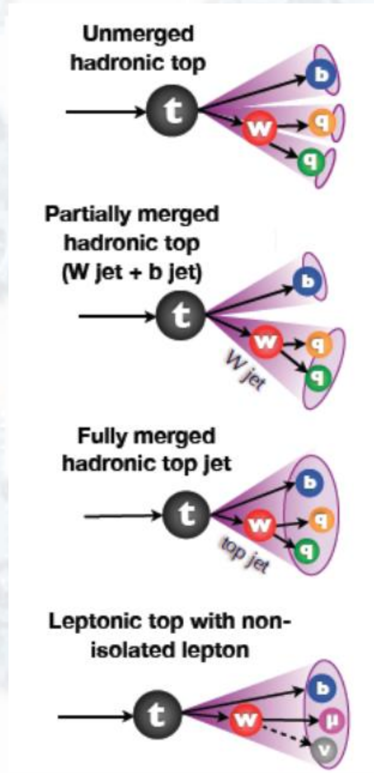
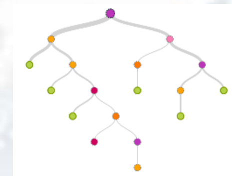


https://atlas.cern/sites/atlas-
public.web.cern.ch/files/blog/wp-
content/uploads/2014/03/boostedTop.png



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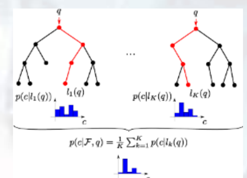
content/uploads/2016/04/decisiontree.png



https://www.researchgate.net/profile/Sven_
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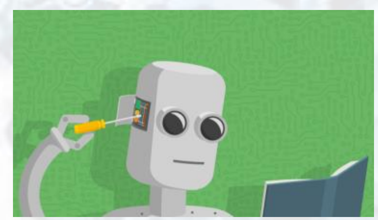

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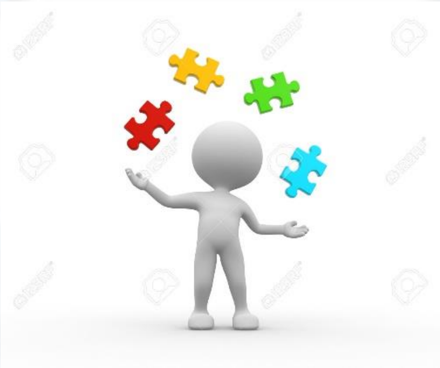

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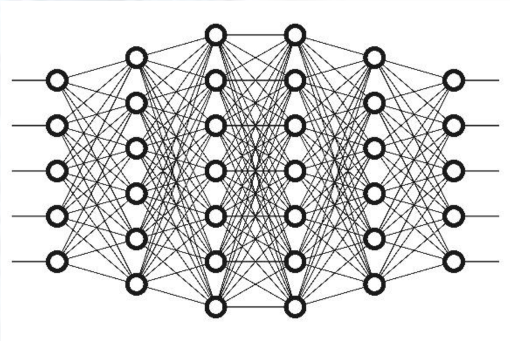

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