Artificial Intelligence in Industry-4.0

Report

RF-modulation classifier

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Industry 4.0

The term "**Industry 4.0"** originated **in 2011 at the Hanover Fair in Germany**.

Industry 4.0 is known as **"Industrie 4.0"** in Germany, "**Connected Enterprise**" in the United States and the **"Fourth Industrial Revolution**" in the United Kingdom

Industry 4.0 or "Industrie 4.0 came as a result of the Germany initiative to **enhance competitiveness** in a **manufacturing industry**. Germany Federal Government vision for a **high-Tech strategy for 2020** gave birth to the buzzword **"Industrie 4.0".**

Definition

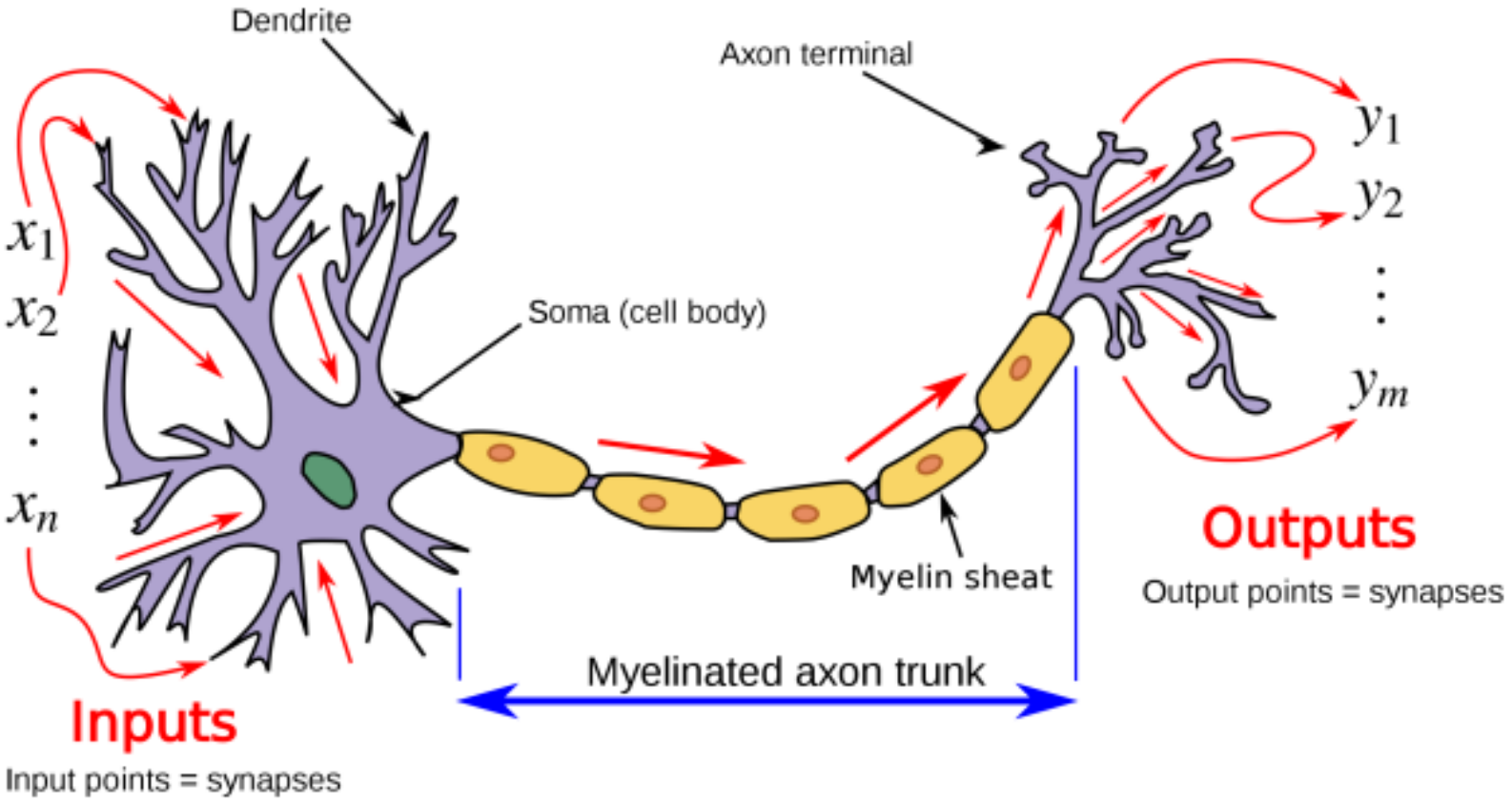
Despite this widely discussed buzzword, **there is no clear definition of the term.**

Industry 4.0 was defined in terms of **Smart Industry** or "Industrie 4.0" which refers to the **technological evolution from embedded systems to cyber-physical systems.**

Industry 4.0 can also be referred to as "a **name for the current trend of automation** and **data exchange in manufacturing technologies**, including cyber-physical systems, **the Internet of things**, **cloud computing** and **cognitive computing** and creating the **smart factory**"

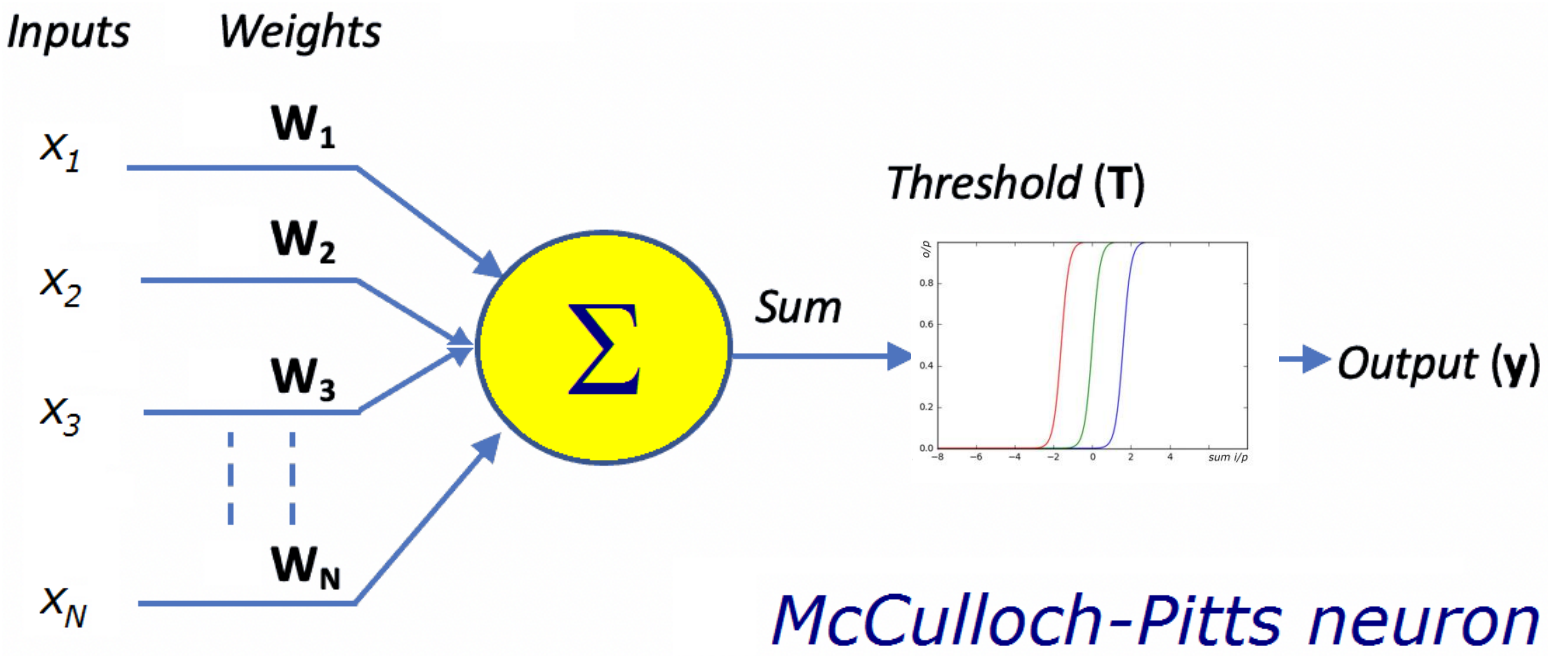
Bio-analogy

- representation of data selection with:
  - sum
  - threshold

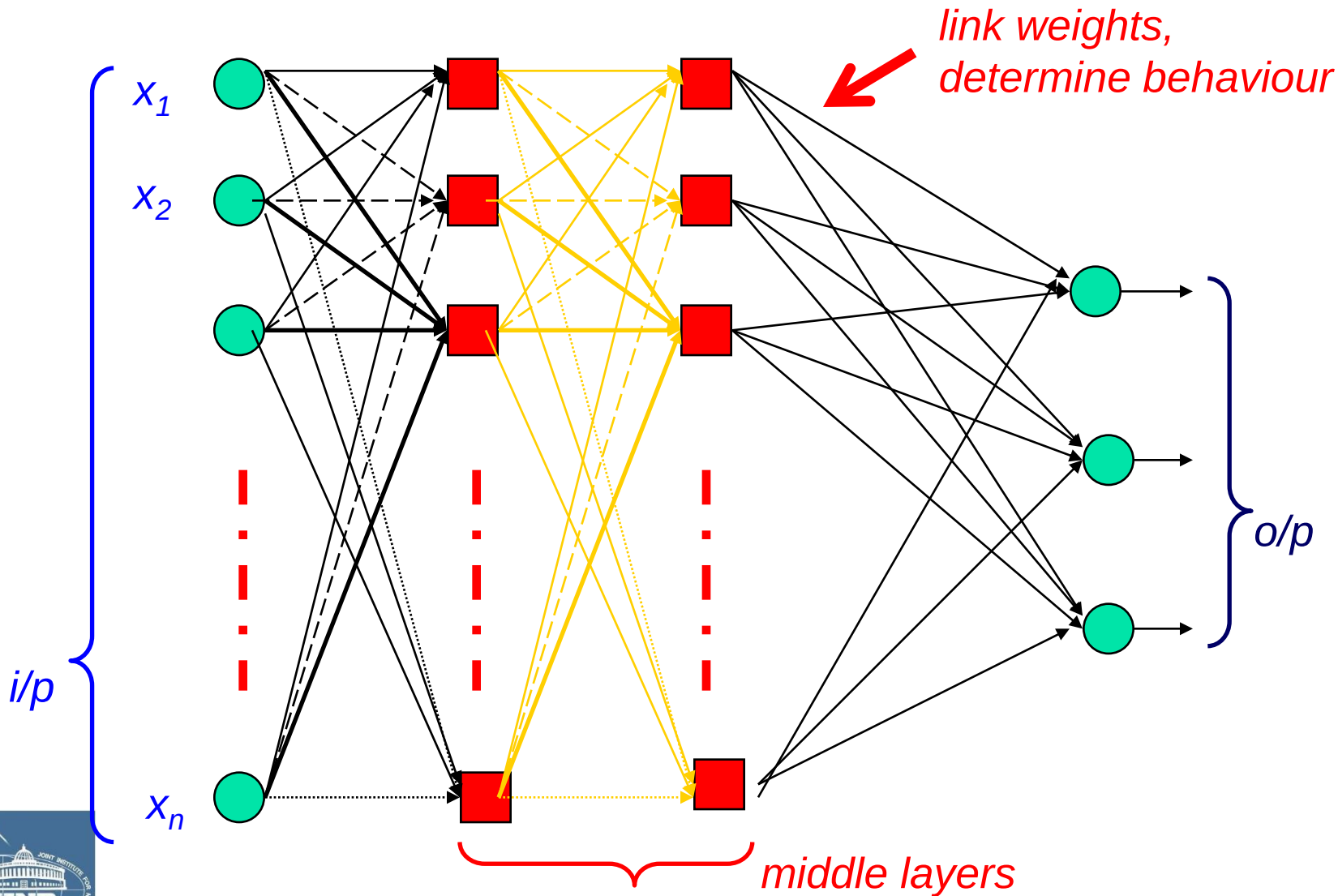


Artificial Intelligence

- representation of data selection with:
  - sum
  - threshold



Multi-layer perceptron



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Hydra accounts

- log onto waves@hydra.jinr.ru
- password = ********
  - choose a student nr.
    - use that directory
    - do not interfere w/ the others
    - we use all the same account
  - "launch" a project: ./addx ELA medium
  - work on the project:
    - compile into libraries: make libs
    - compile test: make test
    - run: make run
    - clean: make clean
  - this was so cool that we had access to this !

C++ resource

Review PROJ

χ^2 fits - are a first (simple)-application of what you learned so far.

Organise in 3 groups and work these projects. Report your results using the template on the main page of the course.

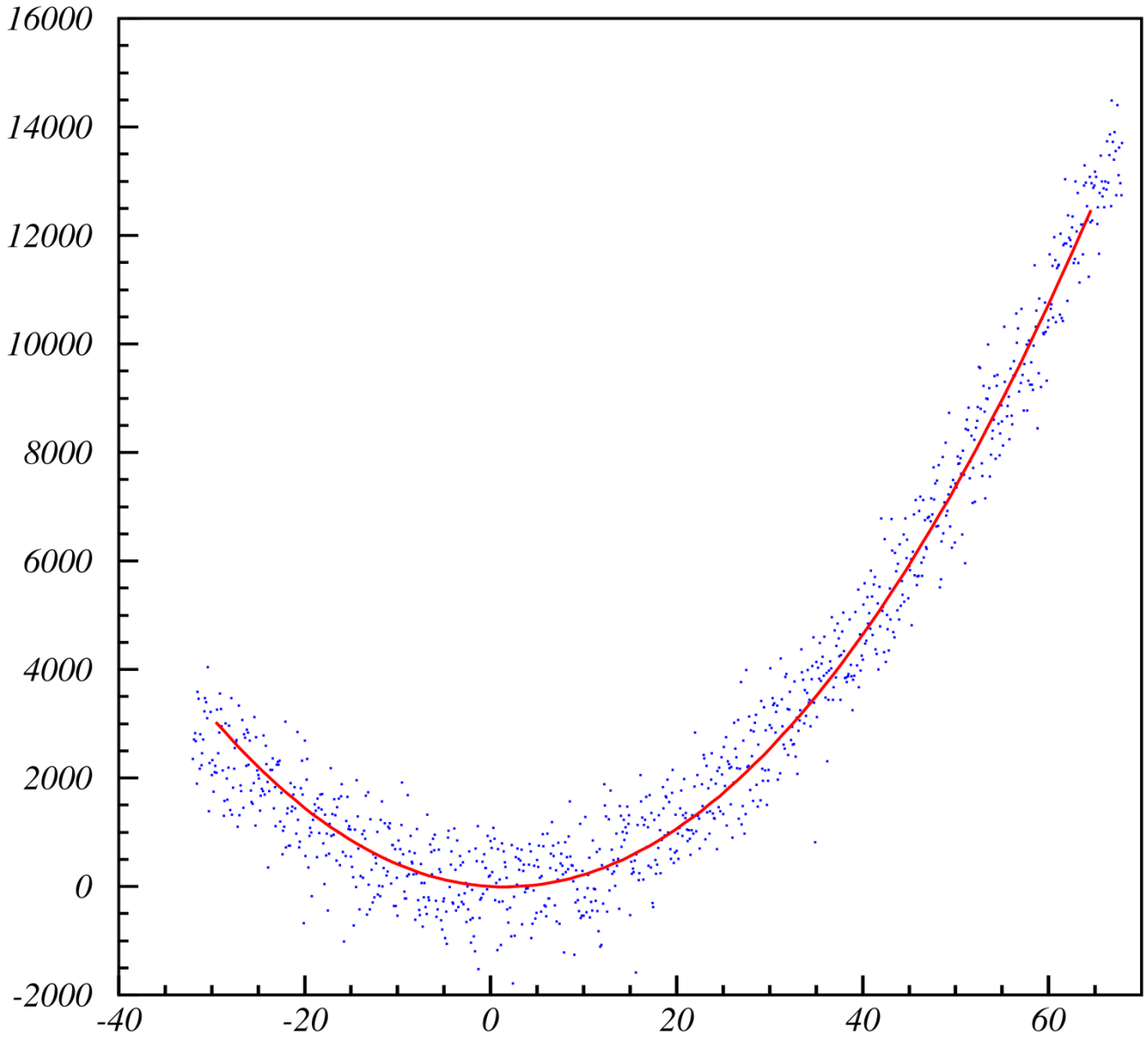
$$\langle \delta y \cdot \delta x^2 \rangle = a_2 \langle \delta x^2 \delta x^2 \rangle + a_1 \langle \delta x \cdot \delta x^2 \rangle$$

$$\langle \delta y \cdot \delta x \rangle = a_2 \langle \delta x^2 \cdot \delta x \rangle + a_1 \langle \delta x \, \delta x \rangle$$

$$\langle y \rangle = a_2 \langle x^2 \rangle + a_1 \langle x \rangle + a_0 \underbrace{\langle 1 \rangle}_{=1}$$

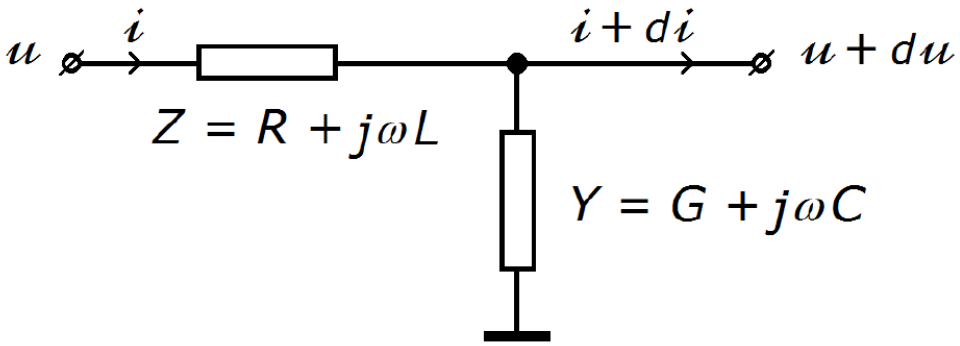
Fit example

- example worked well



SU2 package

- model dispersion of a square wave on a transmission line:



$$-\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \partial_x \equiv \begin{pmatrix} 0 & L \\ C & 0 \end{pmatrix} \partial_t + \begin{pmatrix} 0 & R \\ G & 0 \end{pmatrix} \Bigg| \begin{pmatrix} u \\ i \end{pmatrix}$$

$Z_0 = Y_0^{-1} = \sqrt{L/C}$, line characteristic impedance

$\lambda_d^{-1} = (RY_0 - GZ_0)/2$, dispersion length

$\lambda_a^{-1} = (RY_0 + GZ_0)/2$, attenuation length

$c = 1/\sqrt{LC}$, signal propagation speed

- equation: $\partial_x + \sigma_1(\partial_{ct} + \lambda_a^{-1}) + j\sigma_2\lambda_d^{-1} = 0\,|_\psi$

$\psi = e^{-ct/\lambda_a}\phi$

$\partial_x + \sigma_1\partial_{ct} + j\sigma_2\lambda_d^{-1} = 0\,|_\phi$

- solution:

$\phi = e^{-\gamma^2(1+\sigma_1\beta)\frac{j\sigma_2}{\lambda_d}(x-vt)}\,|_{\phi_0}$

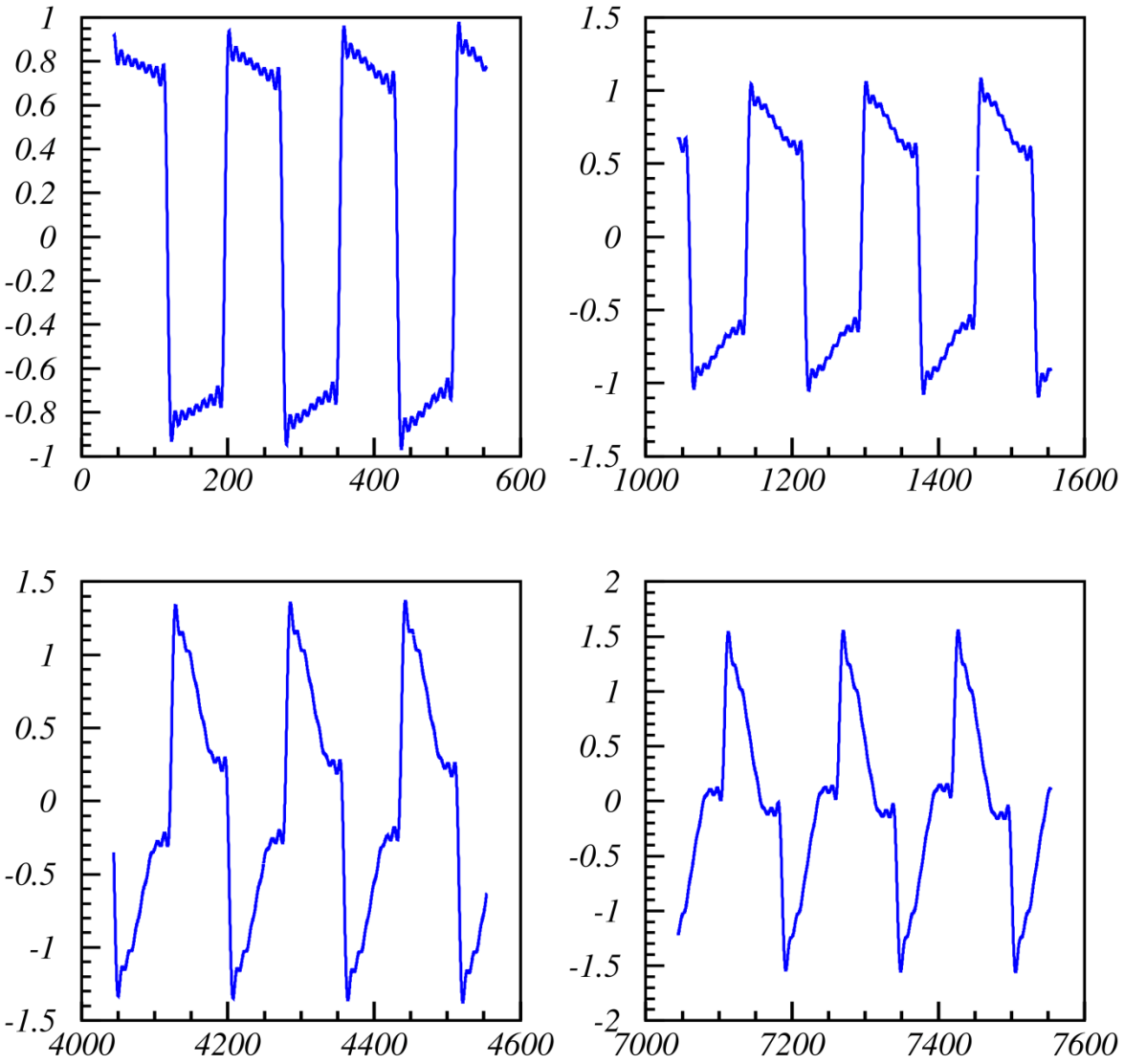
SU2 package

- I used the SU2 package to model the propagator:

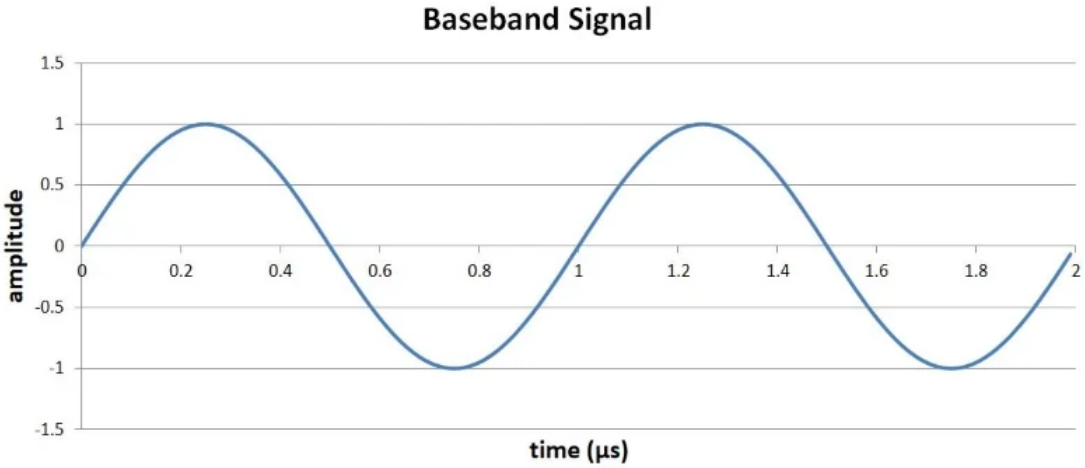
```
auto propagator(real x, real t, real f)}
{
 real gamma = sqrt(1+f*f*Ld*Ld/c/c)
 real beta  = sqrt(gamma*gamma-1) / gamma    ;
 return e^(-(1+sx*beta)*(j*sy)*(x-beta*c*t)  ;
                              *gamma*gamma/Ld)  ;}
```

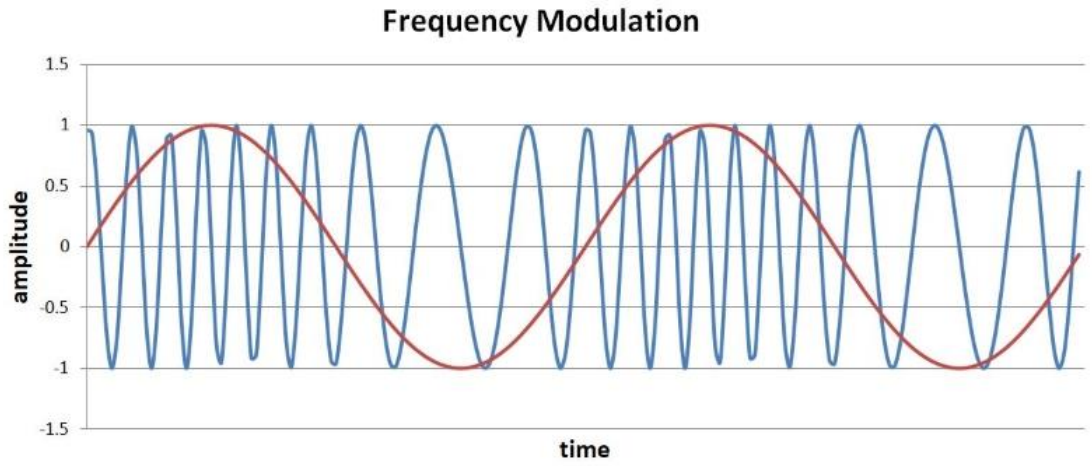
SU2 package

- I obtained a very nice solution of square wave dispersion:



Radio frequency modulation





Shift keying:

- *ASK, amplitude*
- *FSK, frequency*
- *PSK, phase*
- *ASK-LSB*
- *ASK-USB*

Determination of: (ped, A, f, φ)

Magic sample number

- RF wave $y = p + Asin(2\pi ft + \phi)$

sampling	1 : 3.675
f_0	12ooo Hz
Δ	1 / 44100 s

- pedestal: find from average

$$\langle y \rangle = p + A_e sin\left(2\pi ft \frac{t_i + t_f}{2} + \phi\right) sinc\left(\frac{2\pi f \Delta t}{2}\right)$$

$$A_e = \frac{A}{sinc(\pi f \Delta)}$$

- magic N: $\Delta t = 11\Delta$ … $\delta p = 0.0023 A_e$

Determination of: (ped, A, f, φ)

Amplitude

- same N = 11 : $\langle \delta^2 y \rangle = A_e \langle \delta^2 (sin) \rangle$

Frequency

- same N = 11 : $\langle y(y - y_{k\Delta}) \rangle = pA_e(\langle sin \rangle - \langle sin_{k\Delta} \rangle) + A_e^2(\langle sin^2 \rangle - \langle sin \cdot sin_{k\Delta} \rangle)$

$$\simeq A_e^2 sin^2\left(\frac{2\pi f k\Delta}{2}\right)$$

$$\simeq \pi k\Delta A_e^2 sin(2\pi f k\Delta) \cdot \delta f$$

(k = 1 ; max sensitivity)

Determination of: (ped, A, f, φ)

Phase

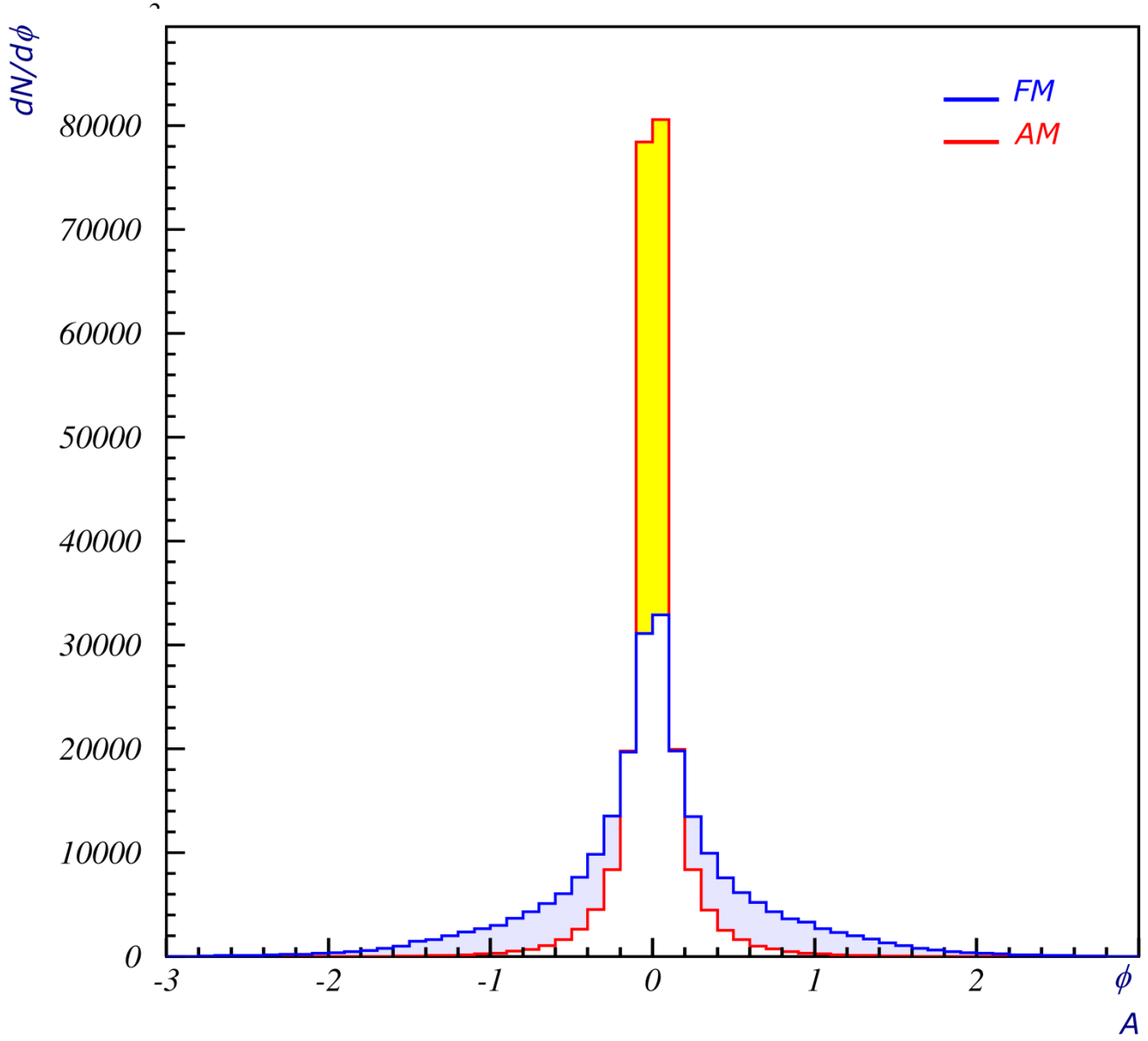
- $\delta\phi = \phi_{current} - \phi_{previous}$

$$\langle\, y \cdot cos(\pi f t)\,\rangle \simeq \frac{A_e}{2} sin\phi$$

- next: form features

Determination of: (ped, A, f, φ)

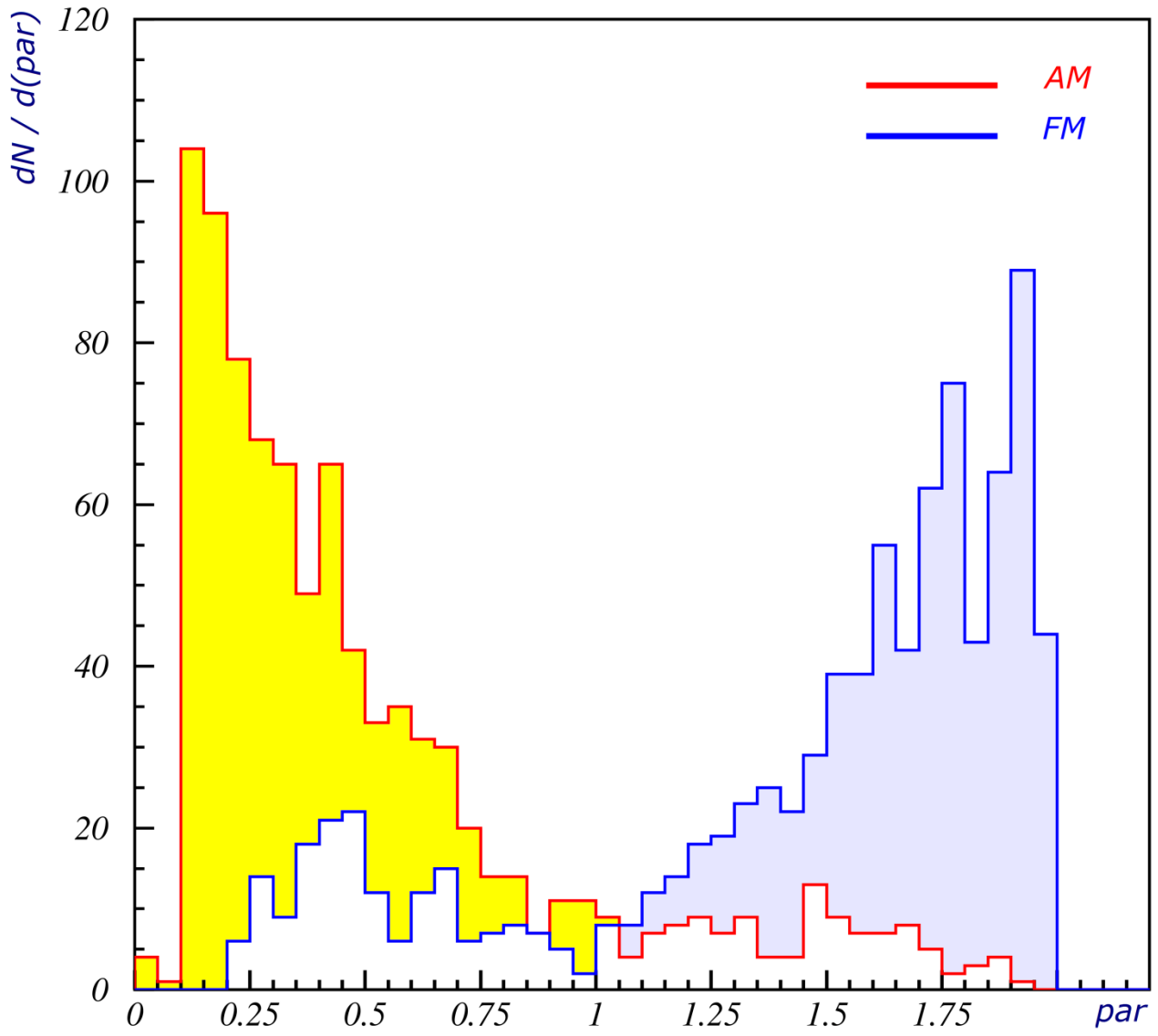
Distributions



ANN features: example

Parameter - 11

```
phi 1 = (L2-L1) * d_p
        L1 = where d
        L2 =
    2 = <distr.> in t
    3 = <N_phi> - <1/
    4 = <N_phi*delta^
```

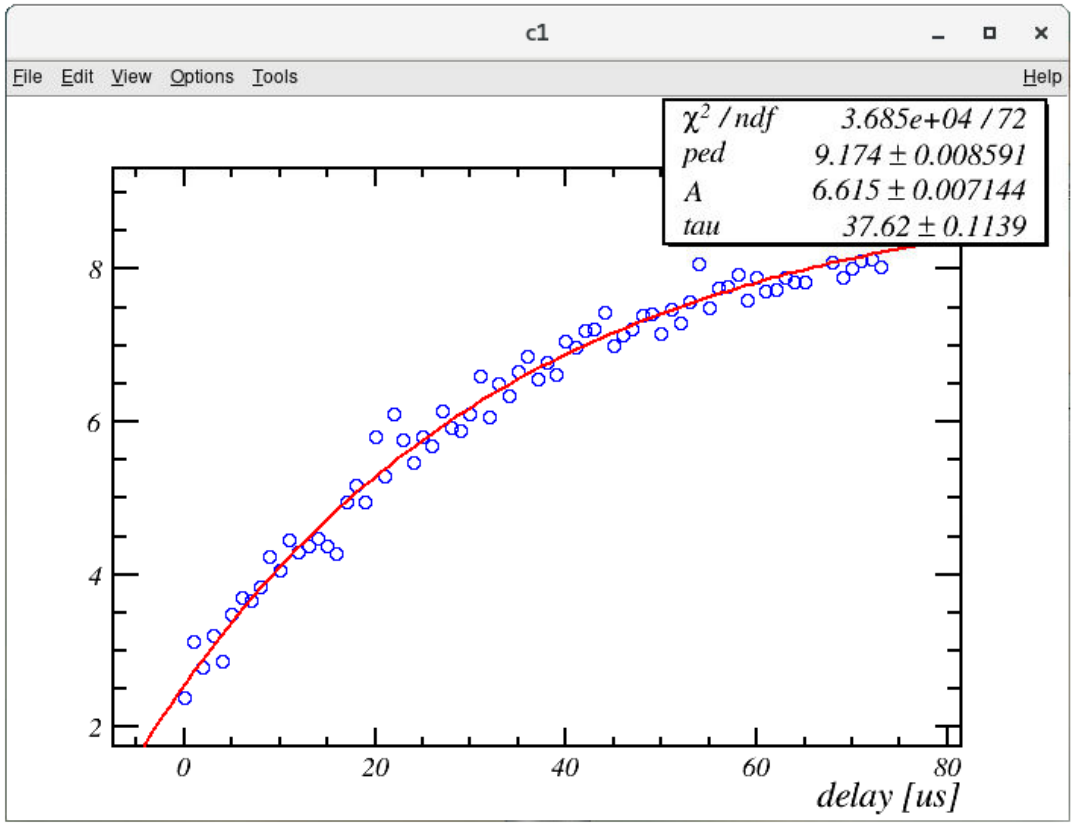


ROOT package

- I downloaded from CERN the ROOT-5.34 (Windows)

- I learned how to write my own macro and do fits

```
// _____________________ ROOT FITS _____________________

void myfit() {

// TGraph gr  ("data.txt", "%lg %lg");
// TGraph grr ("test.txt", "%lg %*lg %lg")
// TGraph grrr("test.txt", "%lg %*lg %*lg %lg")

gStyle->SetOptFit   (1)
gStyle->SetLineWidth(2)


TGraphErrors* gr = new TGraphErrors("z4.txt")

Int_t N = gr->GetN()
Double_t x,y
  for (Int_t i=0; i<N; i++) {
    gr->GetPoint     (i,      x,      y)
    gr->SetPointError(i,   0.01,   0.01)
    gr->SetPoint     (i,  x/1.0,      y)


TF1 fit("fit", "([0]-[1]*exp(-x/[2]))", 0, 74)

    fit.SetParName  (0, "ped"  )
    fit.SetParName  (1, "A"    )
    fit.SetParName  (2, "tau"  )

    fit.SetParameter(0, 11.500 )
    fit.SetParameter(1,  9.500 )
    fit.SetParameter(2, 55.400 )

  gr->Fit("fit")
```



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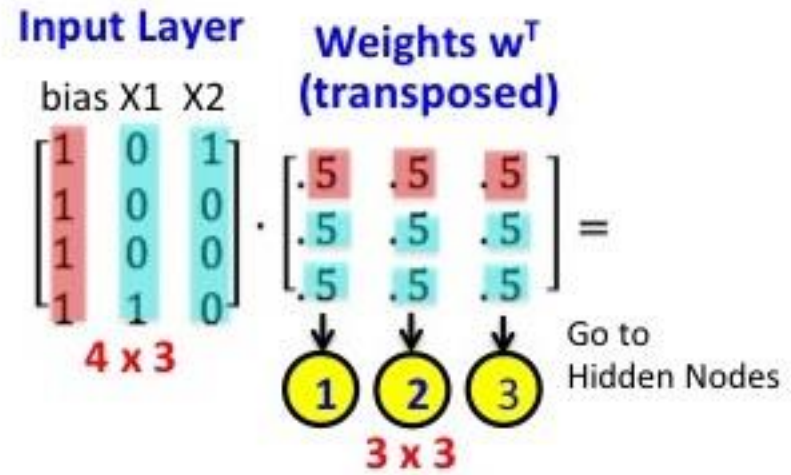
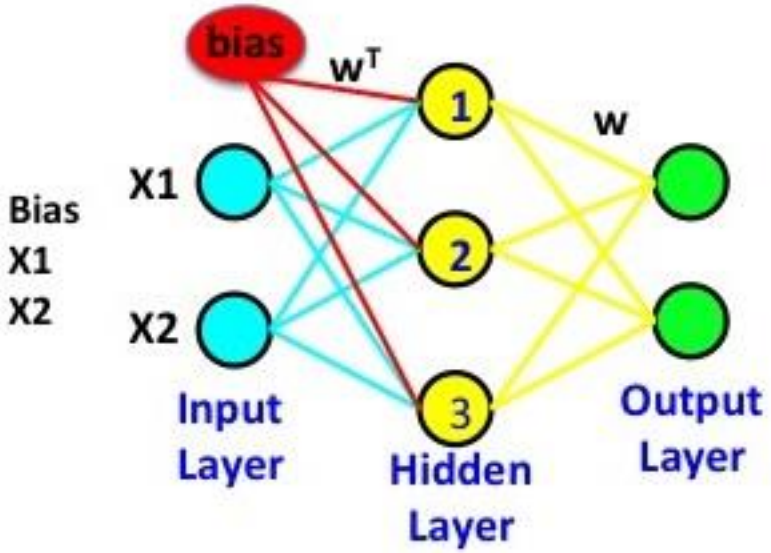
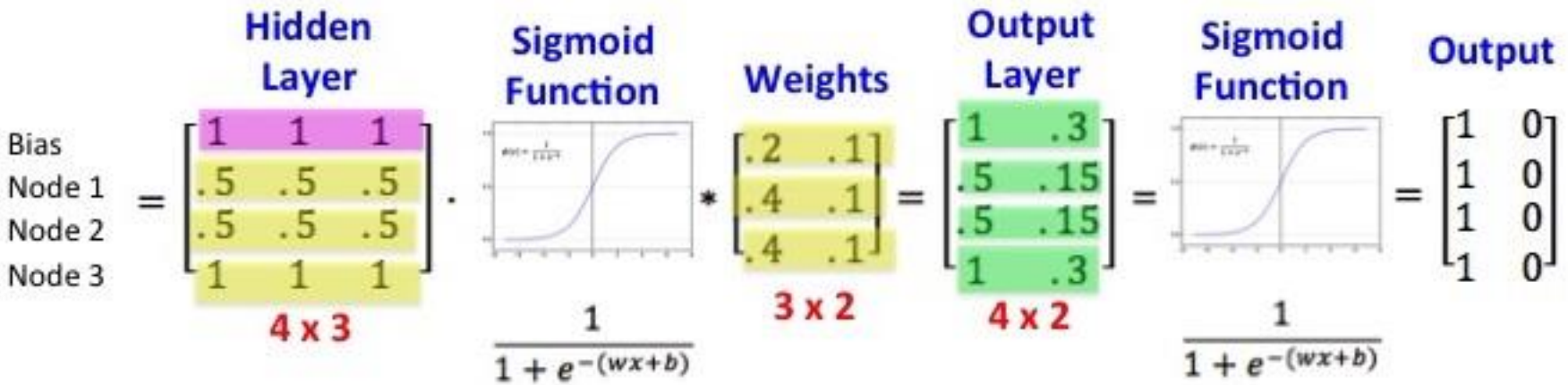
MLP run-through







ROOT MLP

ROOT
Reference Guide

Version master

https://root.cern.ch/doc/master/classTMultiLayerPerceptron.html

Search

Public Types

enum EDataSet { kTraining, kTest }

enum ELearningMethod {
kStochastic, kBatch, kSteepestDescent, kRibierePolak,
kFletcherReeves, kBFGS
}

▸ Public Types inherited from TObject

Public Member Functions

TMultiLayerPerceptron ()
Default constructor. More...

TMultiLayerPerceptron (const char *layout, const char *weight, TTree *data, TEventList *training, TEventList *test, TNeuron::ENeuronType type=TNeuron::kSigmoid, const char *extF="", const char *extD="")
The network is described by a simple string: The input/output layers are defined by giving the branch names separated by comas. More...

Learn a function

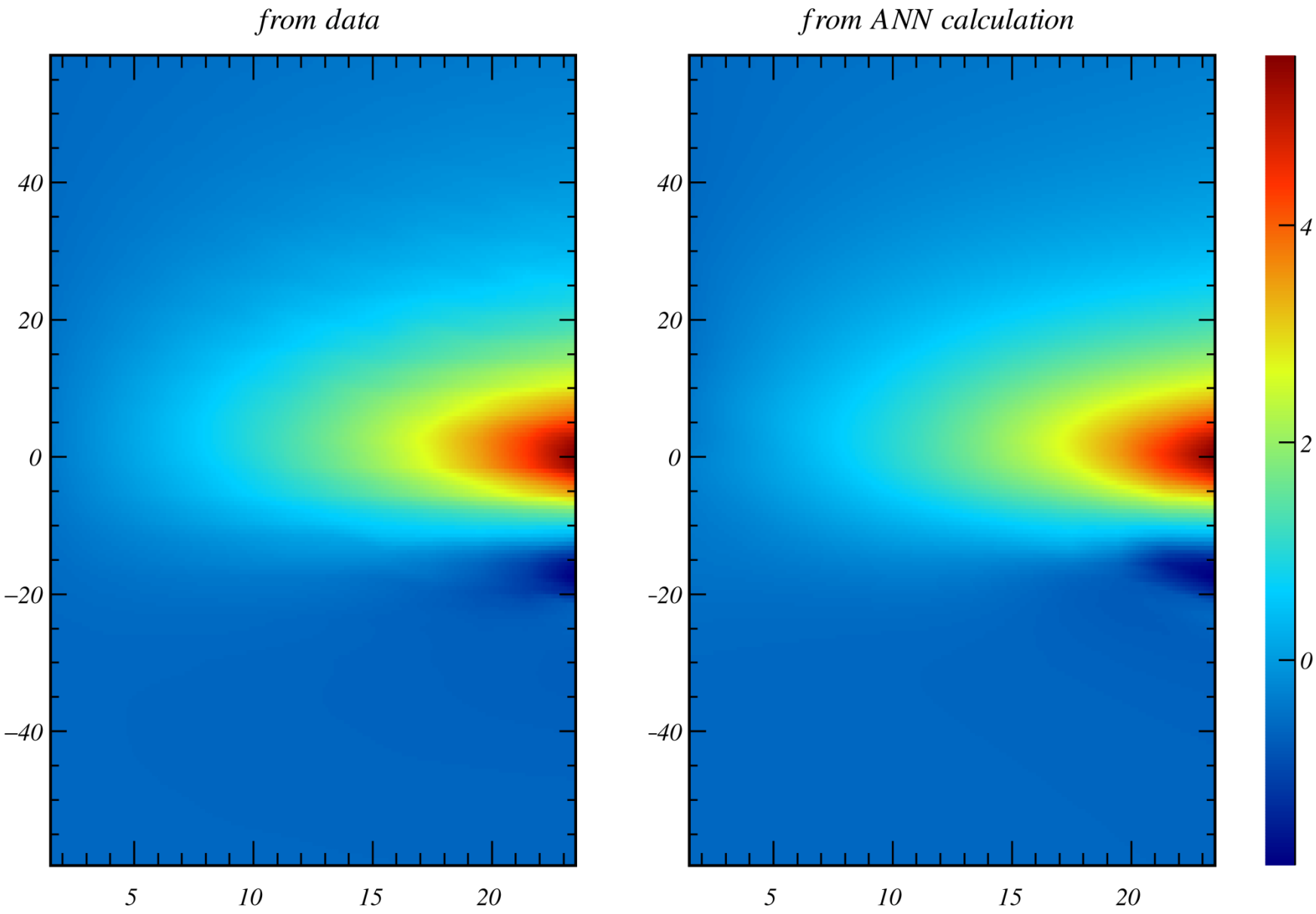
- *example: radial field of a magnet*

```
// read data ____________________________________________________

TTree* t = new TTree("treename", "description")                ;

    // (r,z) = cylindrical coordinates
    // Br    = radial component of magnetic field

Int_t nlines = t->ReadFile("Br.dat","r:z:Br")                  ;

 // MLP setup ___________________________________________________

 TMultiLayerPerceptron *mlp =
   new TMultiLayerPerceptron("@r,@z:10:10:10:@Br",
                             t                   ,
                            "Entry$%2"           ,
                            "(Entry$+1)%2"        )          ;

     // i/p           = r, z (both normed: @)
     // mid-layers    = 10+10+10 neurons
     // o/p           = Br (normed: @)
     //
     // training set = even,  Entry$%2     = true
     // testing  set = odd , (Entry$+1)%2 = true
```

Regression analysis

```
// set learn method ____________________________________________

mlp->SetLearningMethod(TMultiLayerPerceptron::kBFGS )      ;

    // kStochastic = default
    // kBatch
    // kSteepestDescent
    // kRibierePolak
    // kFletcherReeves
    // kBFGS

          // training ____________________________________________

          mlp->Train( 1000
                      "text,update=100" )                          ;

              //  1000 events
              //  write text to console
              //  updates every 100 epochs
```

Regression analysis

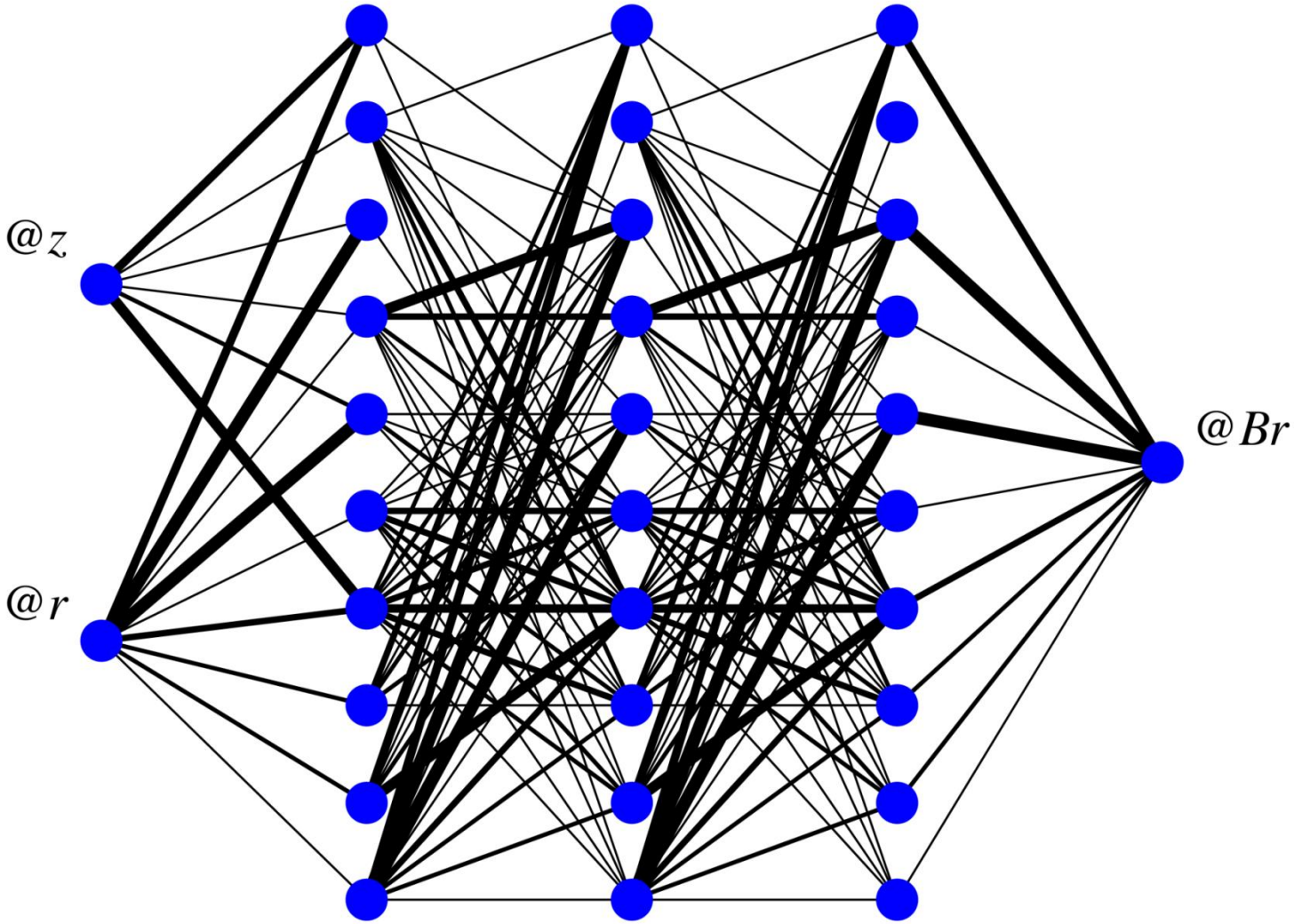


Regression analysis

```
// TMLPAnalyzer ____________________________________________________

TCanvas* mlp_analysis_canvas = new TCanvas("canvasname" ,
                                           "description")  ;

      // give the trained mlp object ____________________________

      TMLPAnalyzer* mlp_analyzer = new TMLPAnalyzer(mlp)          ;


           // init ____________________________________________________

           mlp_analyzer->GatherInformations()                          ;

           // print info ______________________________________________

           mlp_analyzer->CheckNetwork()                                ;

               // x-axis = derivative of the NN with  respect  to  each
               //          input how the NN changes for 1 unit of input
               //            low-impact  variables = low  x
               //            high-impact variables = high x
               //          extreme sensitivity to some variable ?
               //          risk of high systematics ?
               // y-axis = number of entries

           mlp_analyzer->DrawDInputs()                                 ;
```

Regression analysis

```
// show network structure ____________________________________
mlp->Draw()                                                  ;
```



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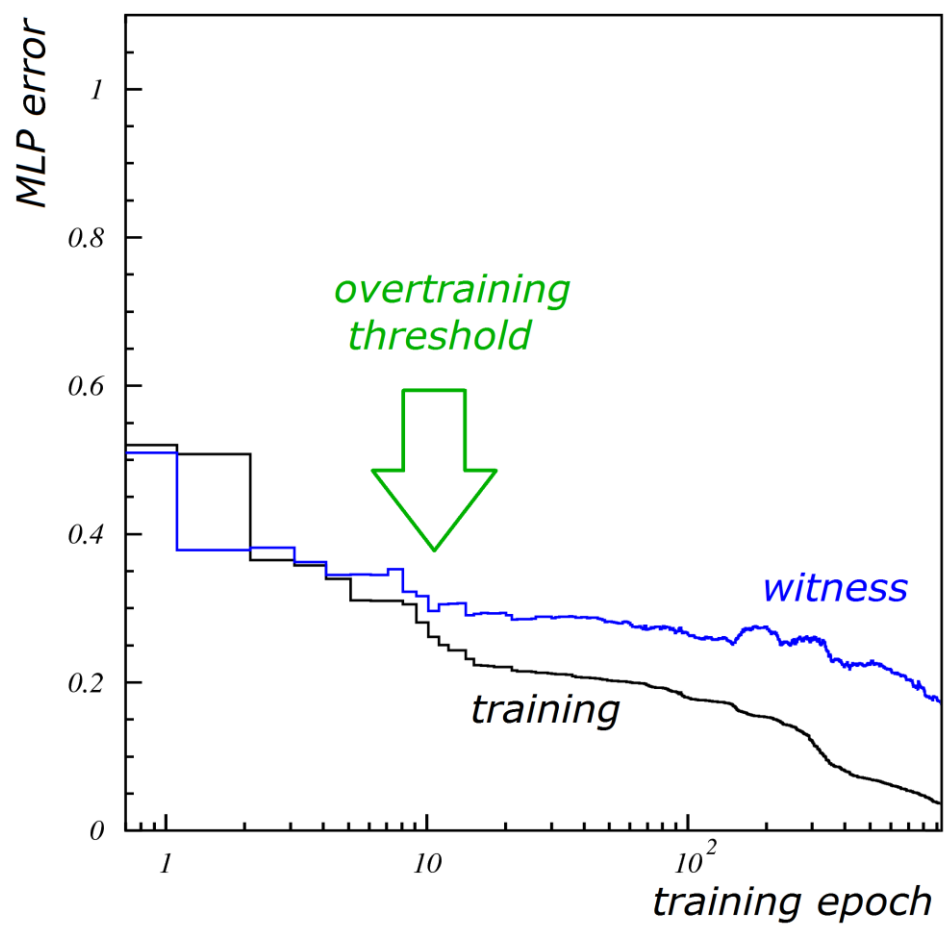
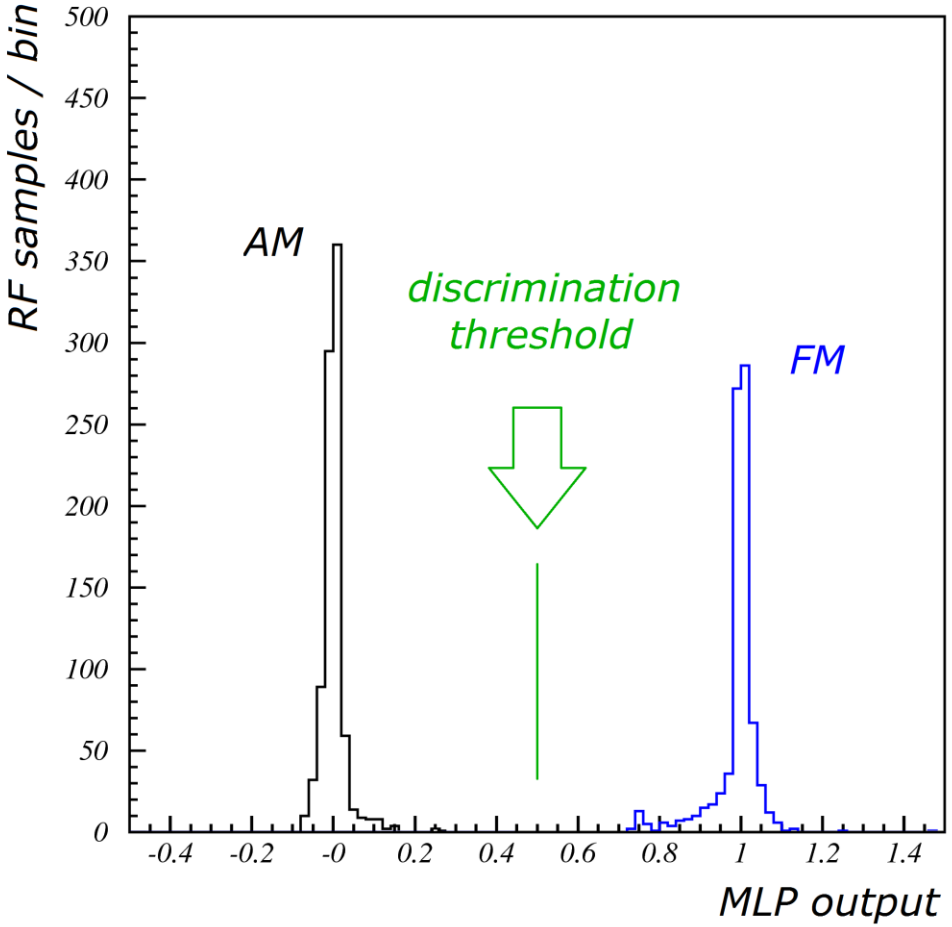
RF-modulation classification

- I tested various combinations of the parameters (ped, A, f, φ):
  - to form features for the multi-layer perceptron and
  - train a neural network to discriminate:
    - ▷ AM vs. FM modulation

- I evaluated the neural network and the results were very good.

AM vs. FM classification





neural network training

neural network evaluation

Personal opinions

- I learned more advanced aspects of C++ (separate model compilation, issue limited instantiation, polymorphism, SFINAE)

- We had access to the supercomputing cluster HybriLIT of JINR, which was very cool

- I learned to use the ROOT package from CERN and the Multi-Layer Perceptron utilities inside it

- We were given example data and code for a number of neuro-software applications – of which I detailed here the RF-modulation classifier

- The professors were very good and friendly, I highly recommend this student training programme !