Advanced Methods in Data Analysis

Outline of the course:

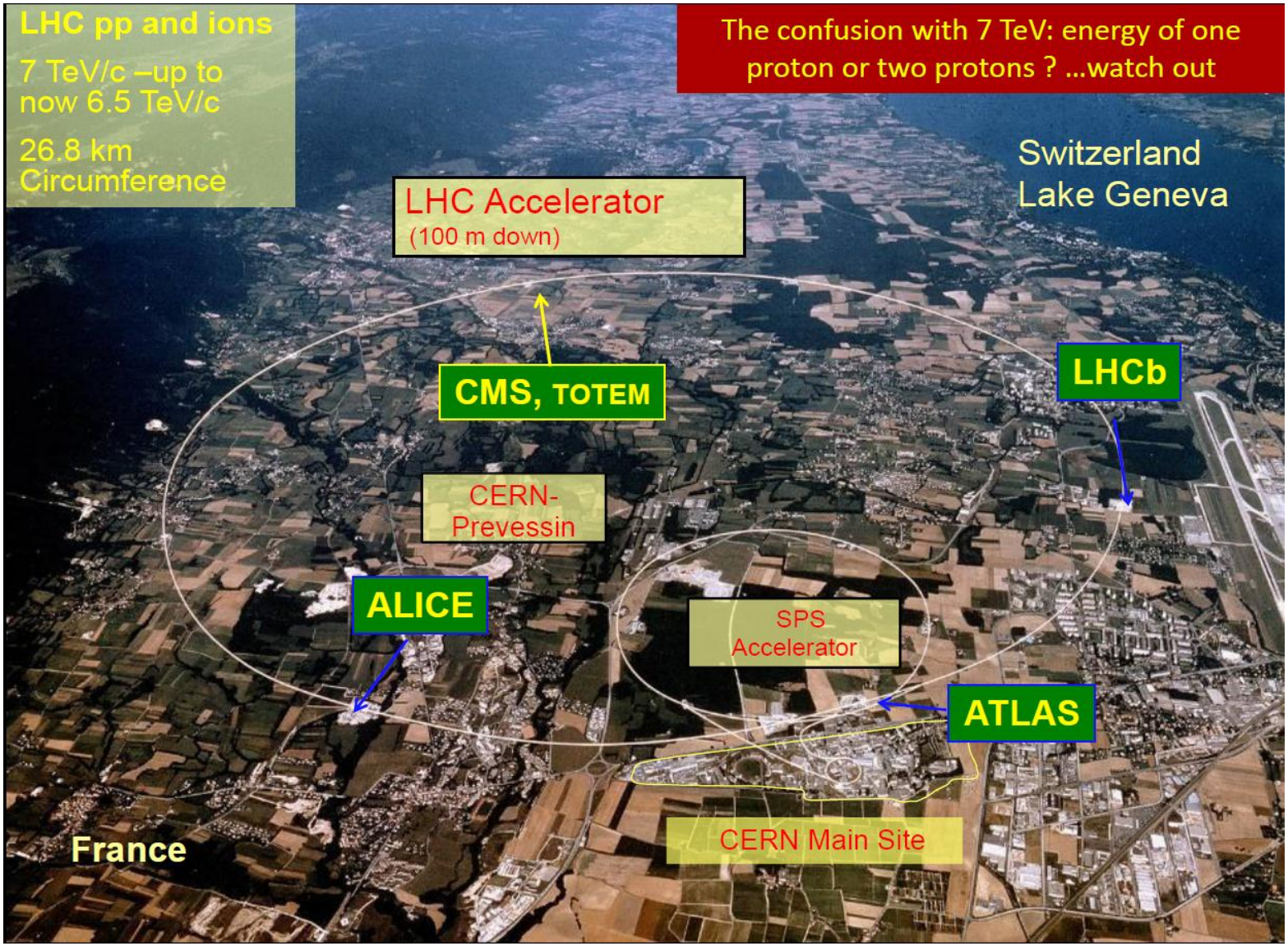
1. **Statistics and Data Analysis**
2. **Multivariate Techniques and Machine Learning**
3. **Physics Modeling, Simulation and Monte Carlo Methods**
4. **Regression, Classification, Clustering and Retrieval**

First three parts will focus on applications in physics, mostly in High Energy Physics.

The last part will cover few typical „Data Science" problems and solutions.

Acknowledgement: slides below „borrowed" from different courses on advanced analysis methods in HEP and Data Science.

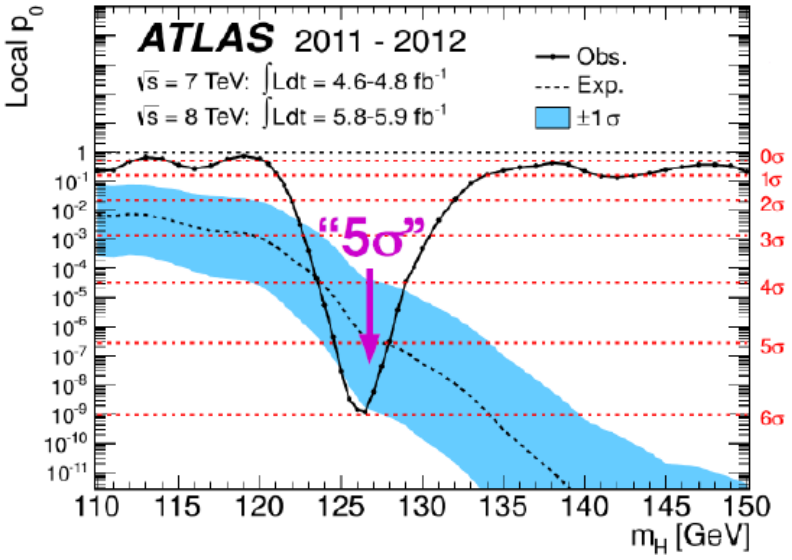
Part 1: Statistics and Data Analysis



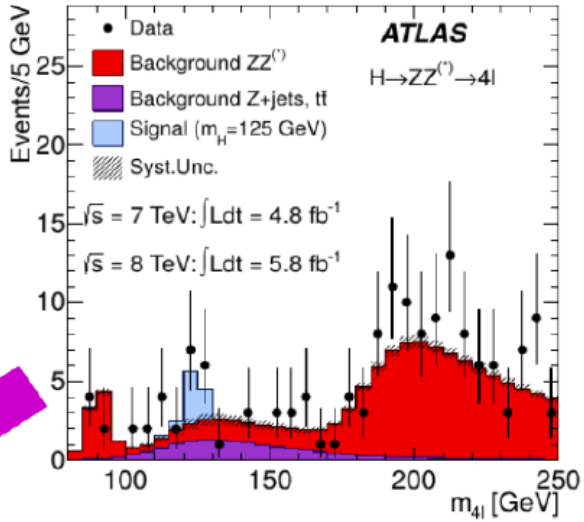
Part 1: Statistics and Data Analysis

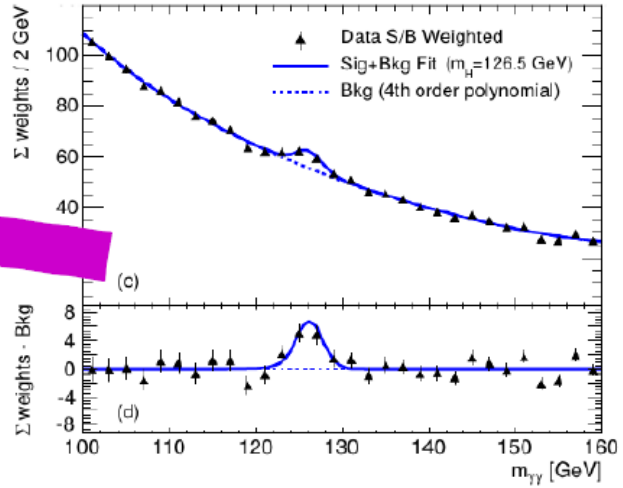
Statistical methods play a critical role in many areas of physics

Higgs discovery : **"We have 5σ" !**



Phys. Lett. B 716 (2012) 1-29

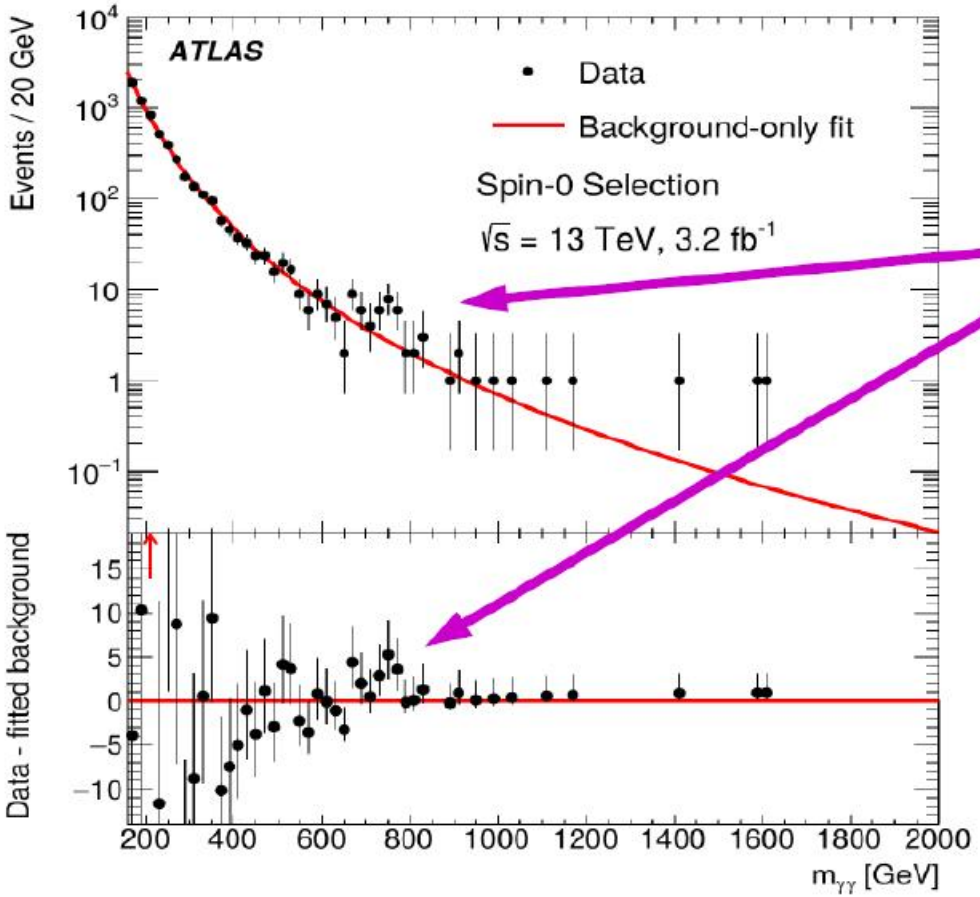




From N. Berger, CERN Summer School, 2019

Part 1: Statistics and Data Analysis

Sometimes difficult to distinguish a bona fide discovery from a **background fluctuation**…



New Physics ?

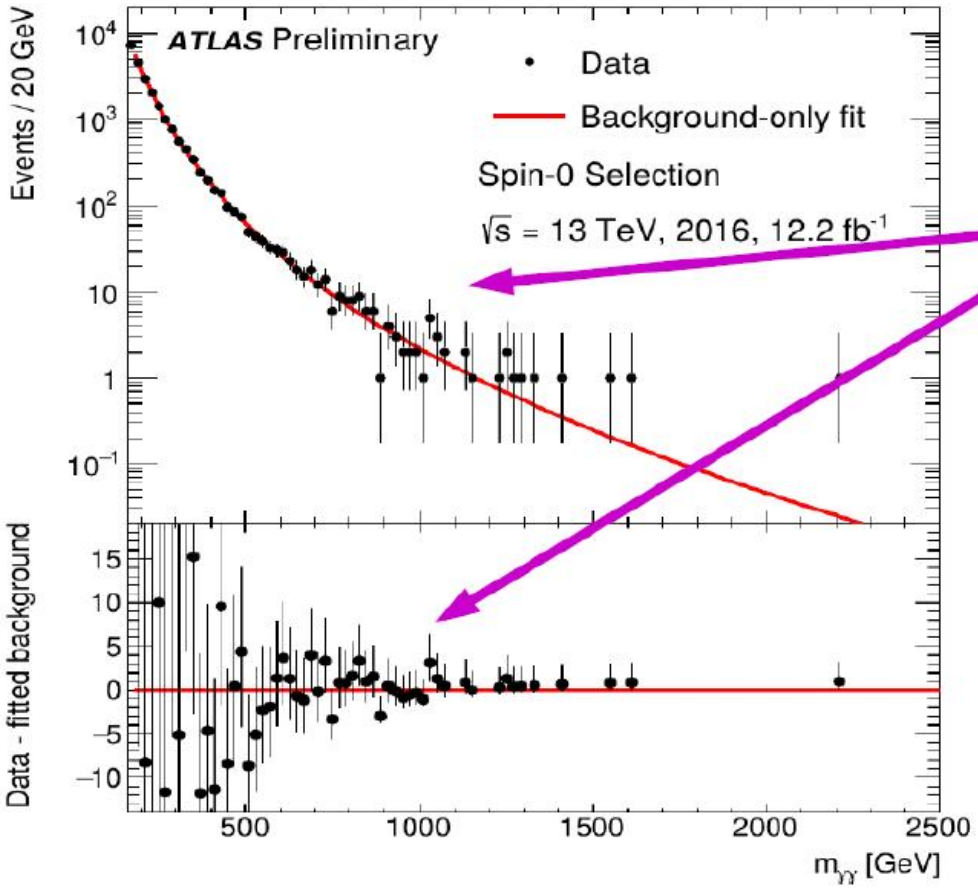
3.9σ ? 2.1σ ?

JHEP 09 (2016) 1

From N. Berger, CERN Summer School, 2019

Part 1: Statistics and Data Analysis

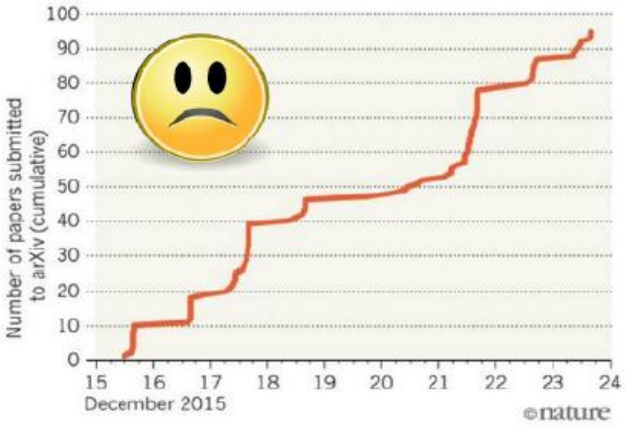
Sometimes difficult to distinguish a bona fide discovery from a **background fluctuation**…



A few months later...

~~New Physics ?~~

~~3.9σ ? 2.1σ ?~~



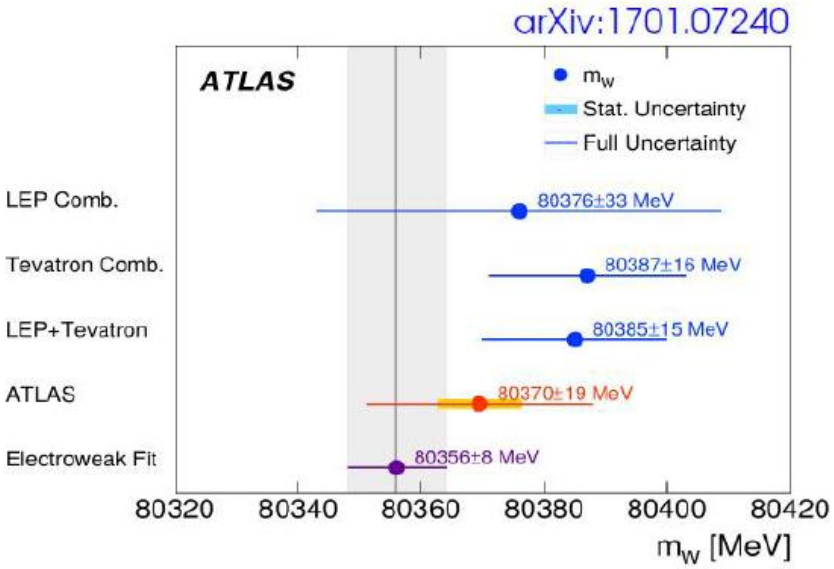
JHEP 09 (2016) 1

From N. Berger, CERN Summer School, 2019

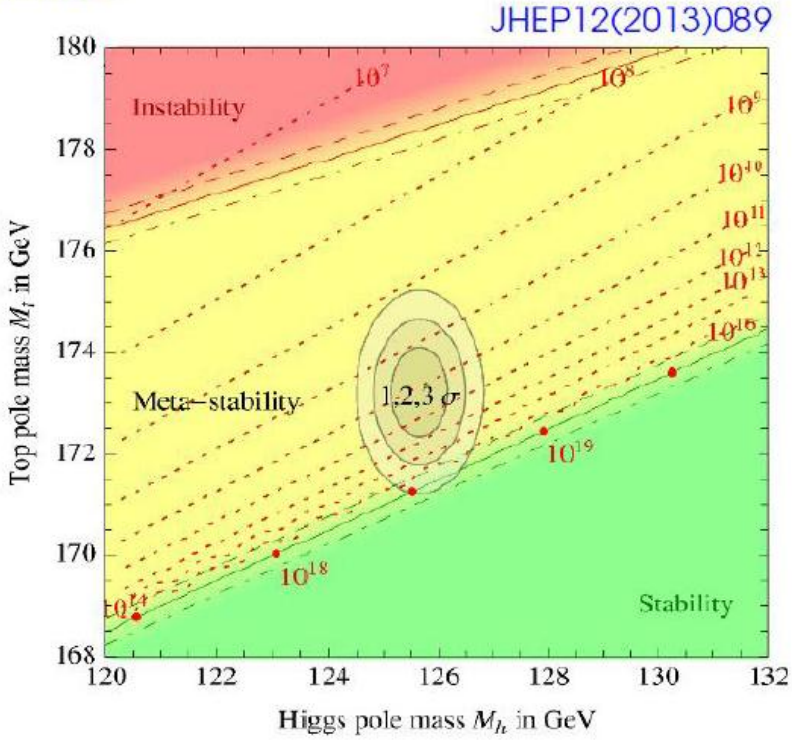
Part 1: Statistics and Data Analysis

Many important questions answered by **precision measurements**, especially if no new peaks found at high mass…

Key point = determination of **uncertainties**



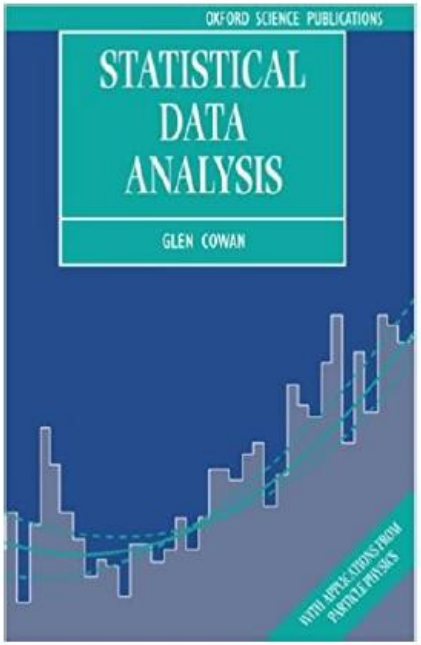
Consistency of the SM…

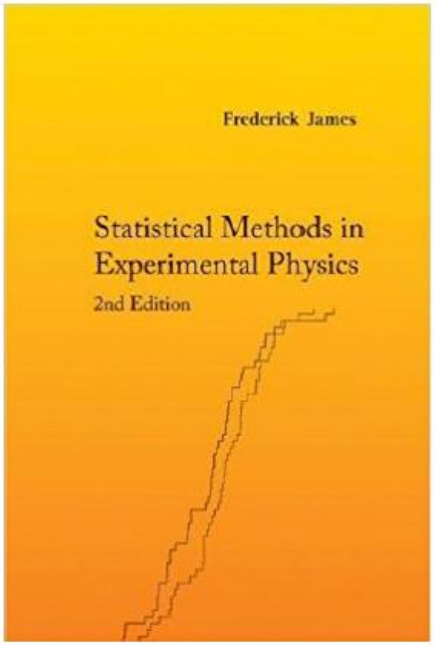


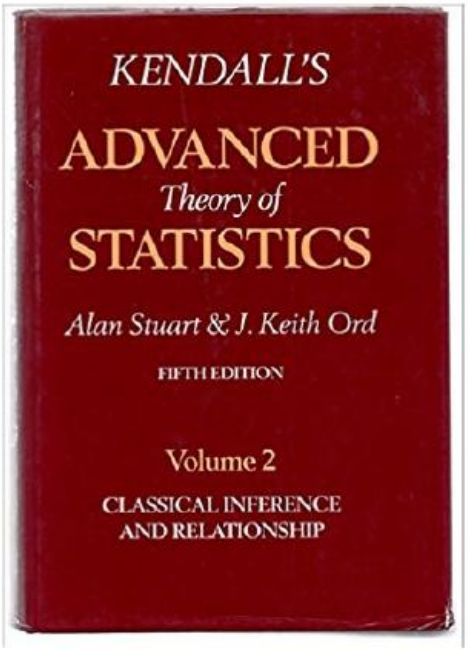
… or the fate of the universe

From N. Berger, CERN Summer School, 2019

Part 1: Statistics and Data Analysis







Some other courses available online:

Glen Cowan's Cours d'Hiver and 2010 CERN Academic Training lectures

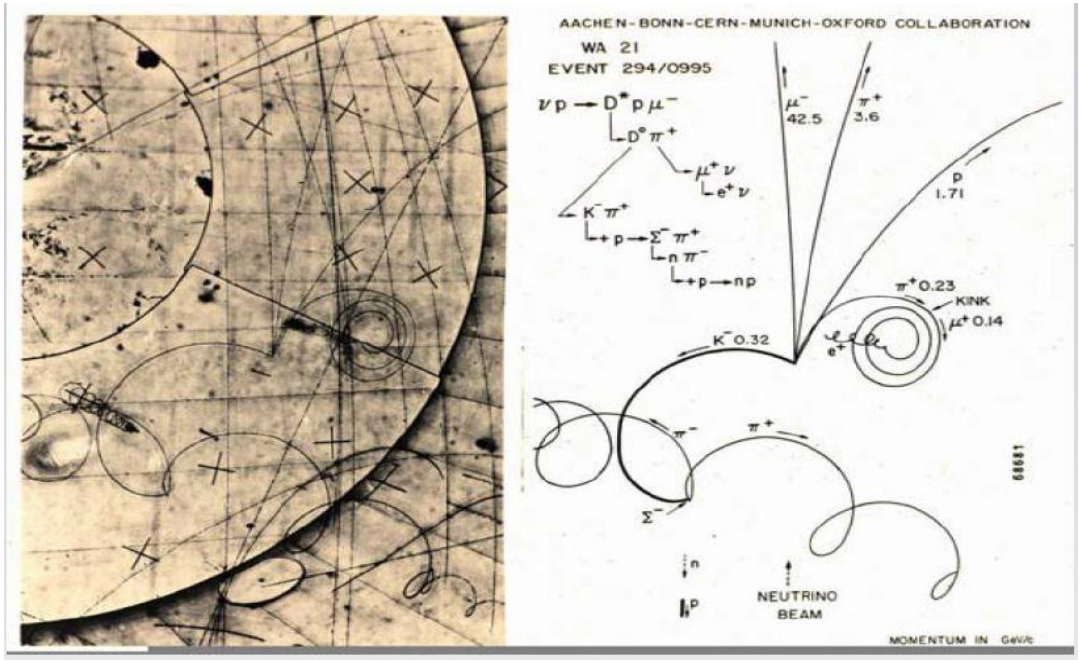
Kyle Cranmer's CERN Academic Training lectures

Louis Lyons' and Lorenzo Moneta's CERN Academic Training Lectures

Part 2: Multivariate Analysis and Machine Learming

In HEP everything started multivariate.

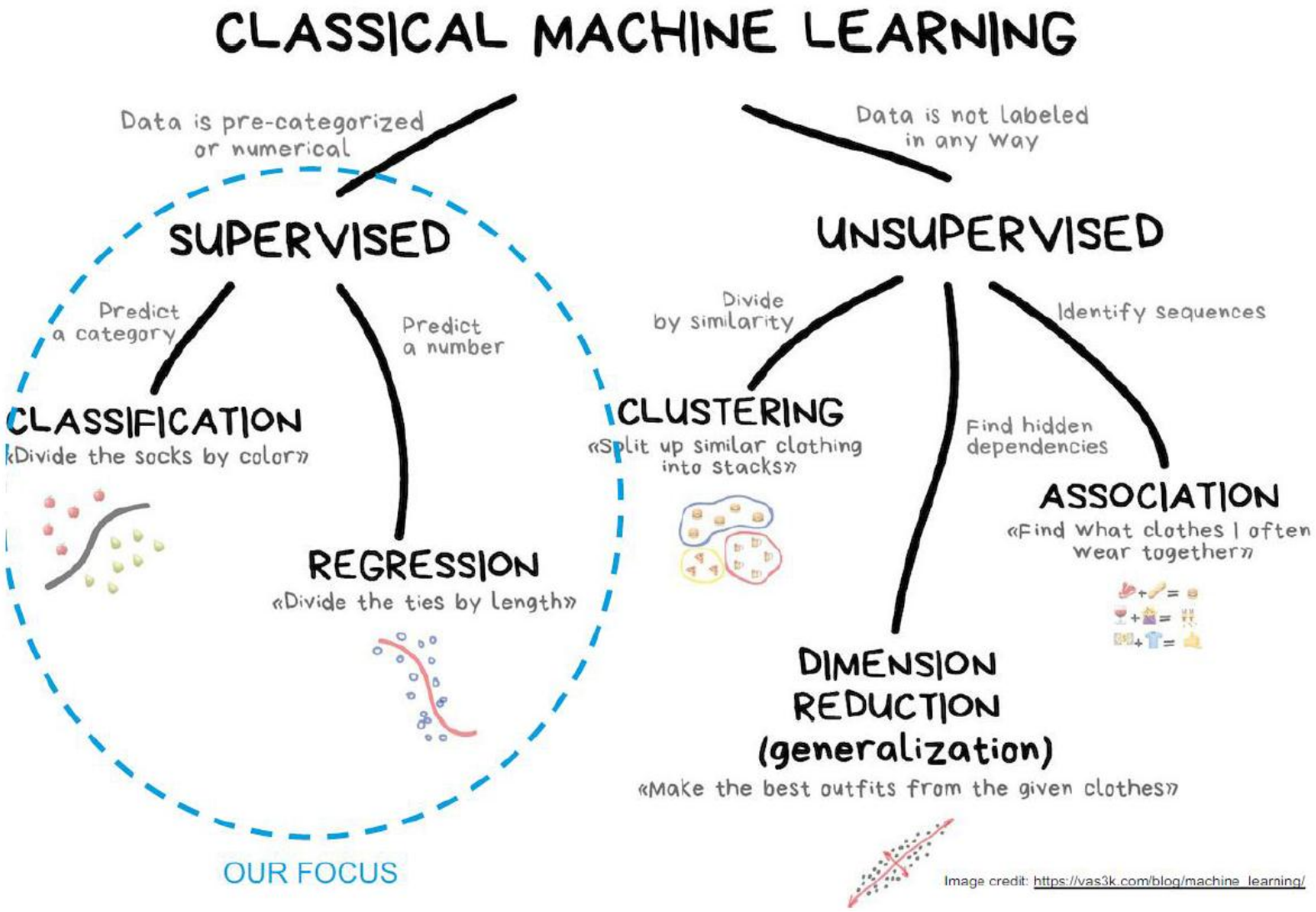
Below: inteligent „Multivariate Pattern Recognition” used to identify particles



https://www.fehcom.net/WA21/wa21_01.html

Nowdays: let computer help you.

Classical Learning



Machine Learning

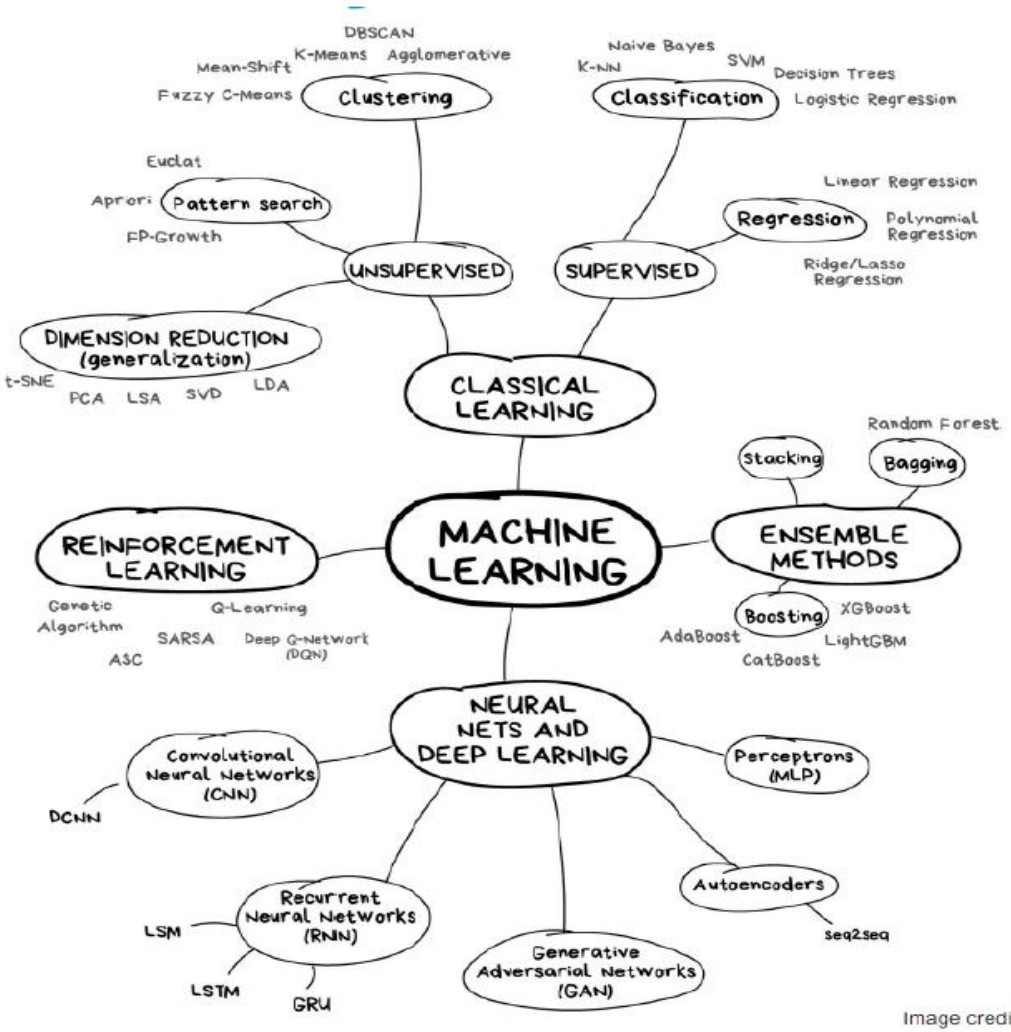


Image credit: https://vas3k.com/blog/machine_learning/

Classifiers and their properties

H. Voss, Multivariate Data Analysis and Machine Learning in High Energy Physics
http://tmva.sourceforge.net/talks.shtml

Criteria		Classifiers								
		Cuts	Likeli-hood	PDERS / k-NN	H-Matrix	Fisher	MLP	BDT	RuleFit	SVM
Perfor-mance	no / linear correlations	😐	🙂	🙂	😐	🙂	🙂	😐	🙂	🙂
	nonlinear correlations	😐	☹	🙂	☹	☹	🙂	🙂	😐	🙂
Speed	Training	☹	🙂	🙂	🙂	🙂	😐	☹	😐	☹
	Response	🙂	🙂	☹/😐	🙂	🙂	🙂	😐	😐	😐
Robust-ness	Overtraining	🙂	😐	😐	🙂	🙂	☹	☹	😐	😐
	Weak input variables	🙂	🙂	☹	🙂	🙂	😐	😐	😐	😐
Curse of dimensionality		☹	🙂	☹	🙂	🙂	😐	🙂	😐	😐
Transparency		🙂	🙂	😐	🙂	🙂	☹	☹	☹	☹

What is the model?

- This is not an apple just its graphical representation

Many skills are needed to build a new model, to run it and analyze its results.

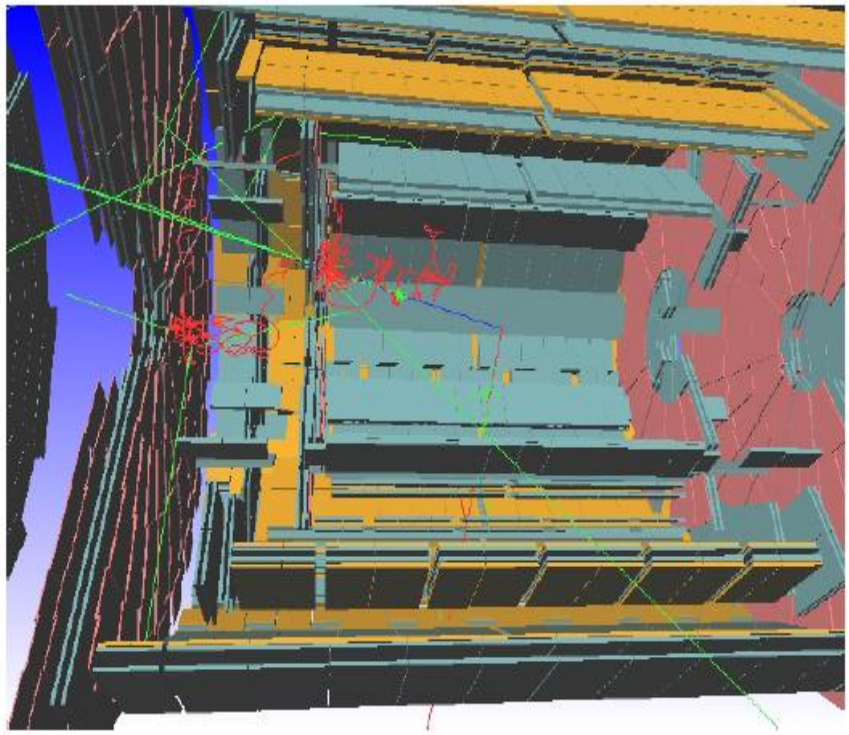
- Computational Science is an emerging, multidisciplinary domain, based on the idea of **"computational thinking"**.
- A computer-based description offers a new language, a new methodology to address scientific challenges, far beyond the scope of traditional numerical methods, and in fields where these classical approaches hardly apply.

B. Chopard et al., coursera lectures, University of Geneva

Part 3: Physics modeling, simulation and and Monte Carlo methods

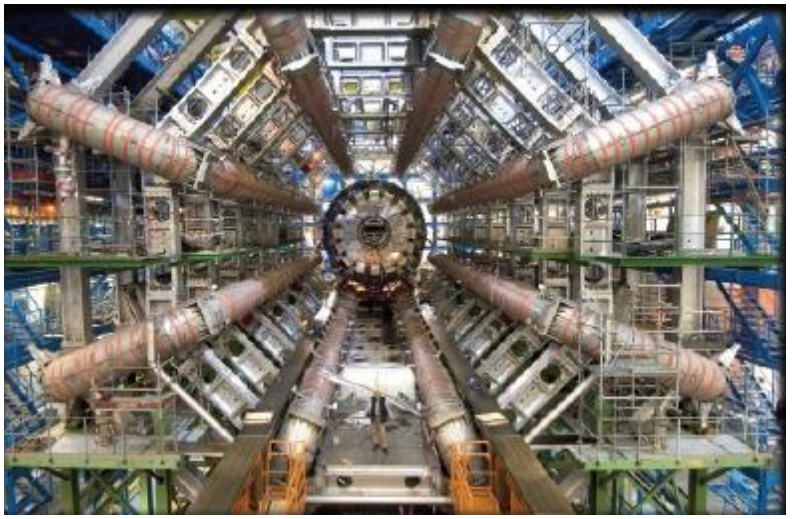
GEANT4

Visualised model of the detector used for simulation



GEANT4 is also used to determine the performance of X-ray and gamma-ray detectors for astrophysics

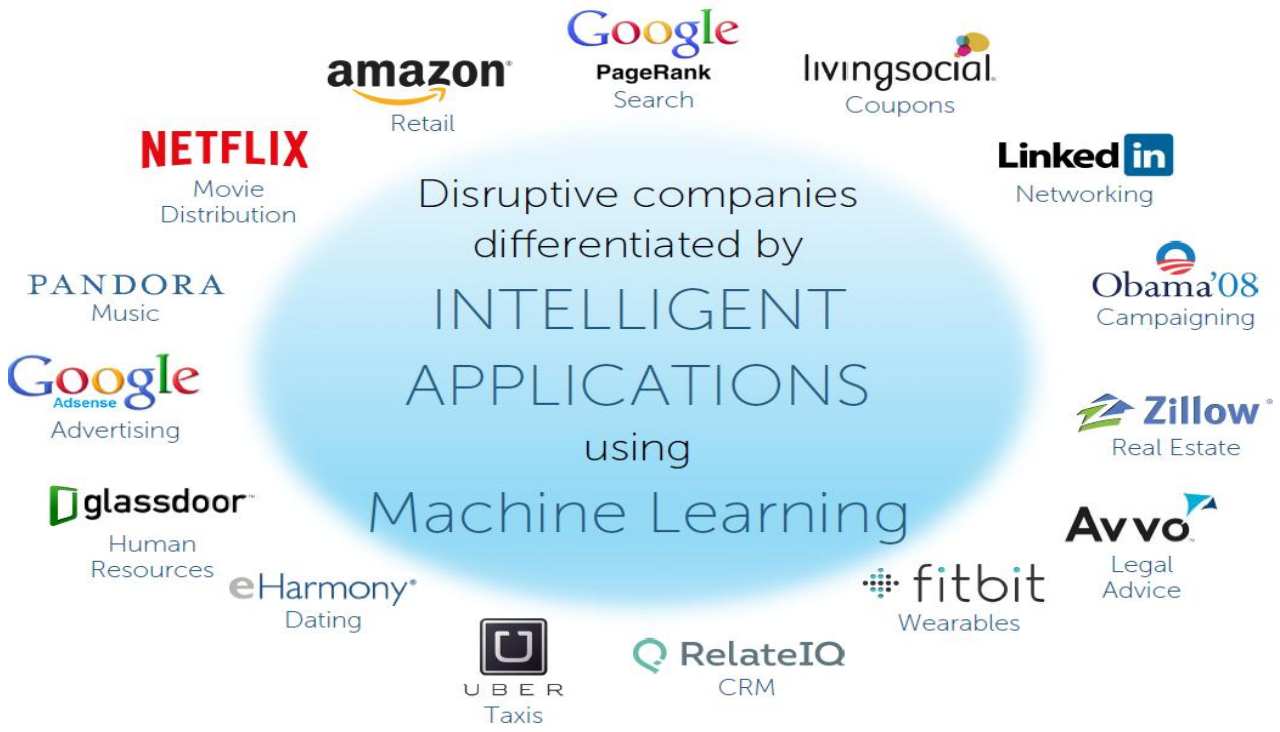
Detector



B. Chopard et al., coursera lectures, University of Geneva

Part 4: Regression, Classification, Clustering

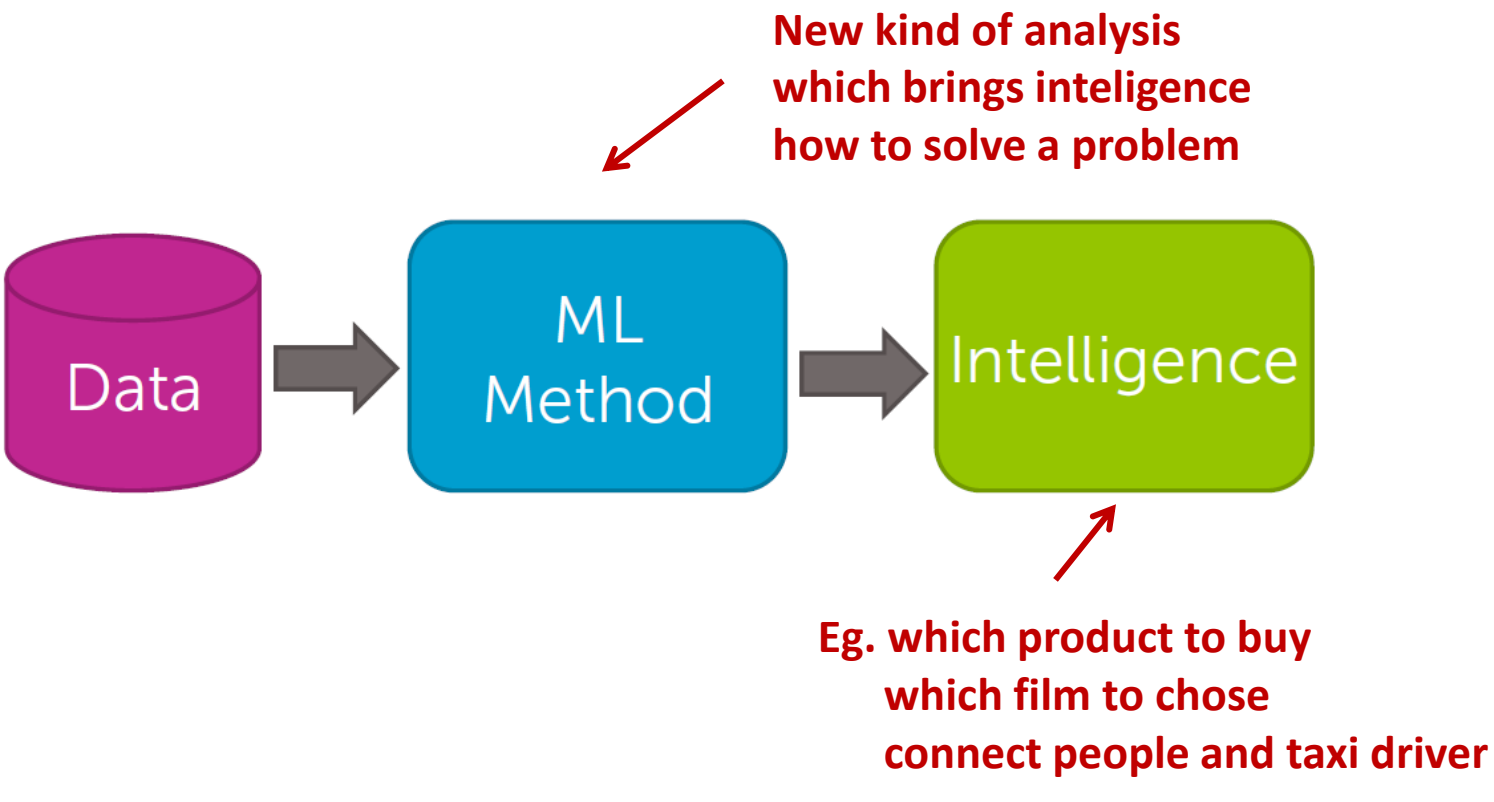
- **Current view on Machine Learning : disruptive inteligent applications are used by leading comercial companies**



course by E. Fox and C. Guestrin, Univ of Washington

Part 4: Regresion, Classification, Clustering

- **Data → inteligence pipeline**



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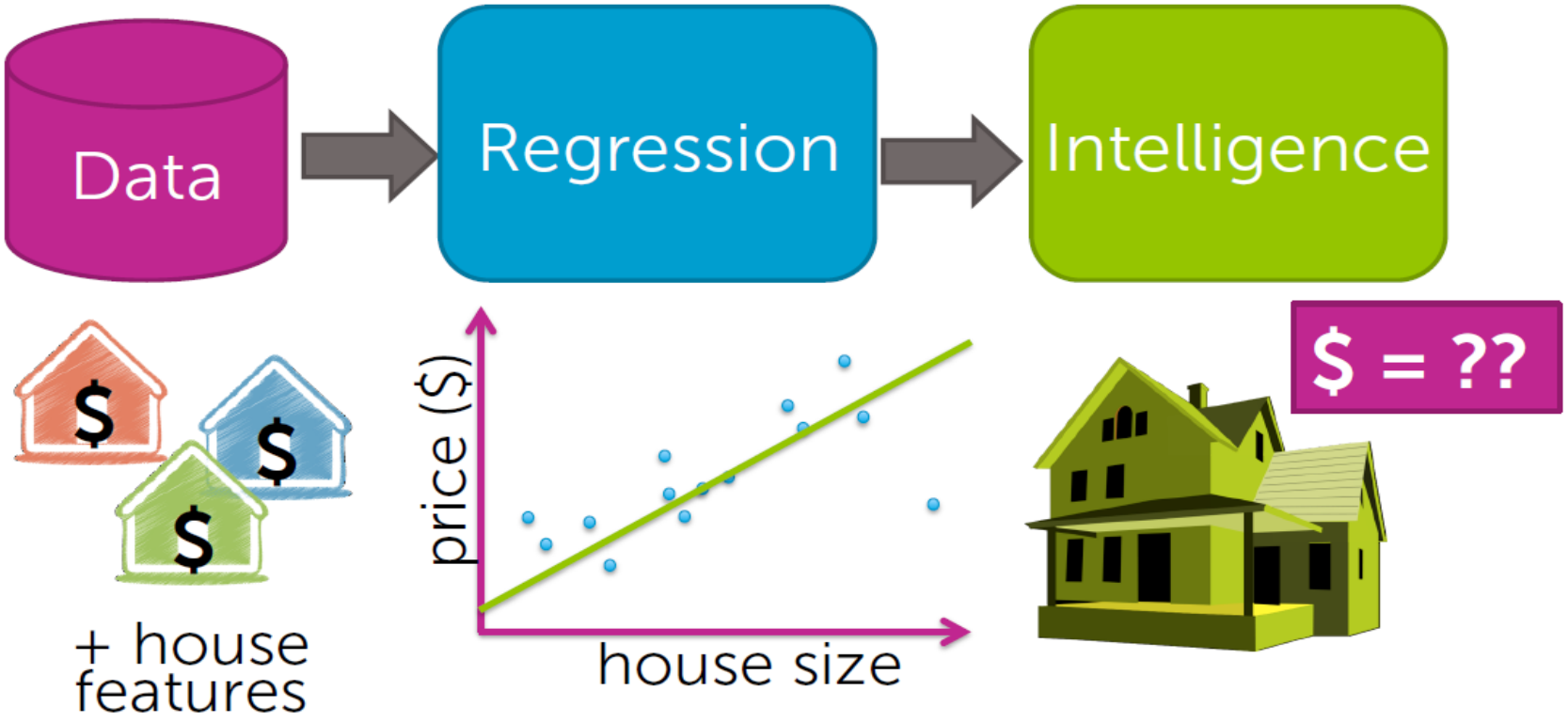
Regression

Case study: prediction for the house price



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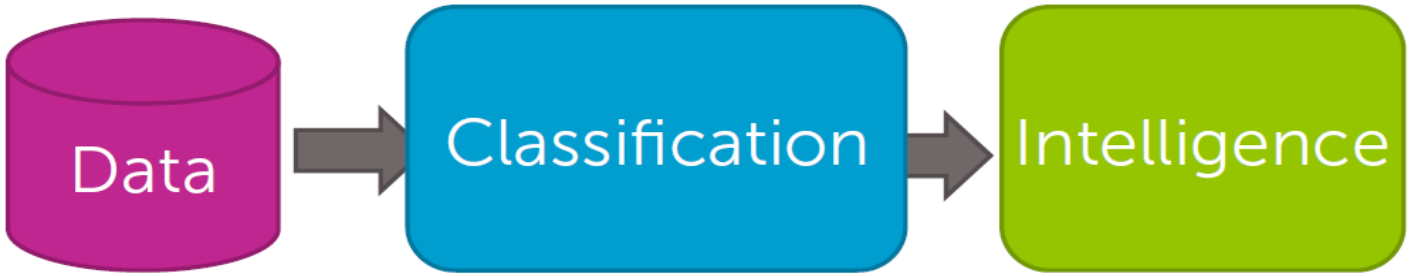
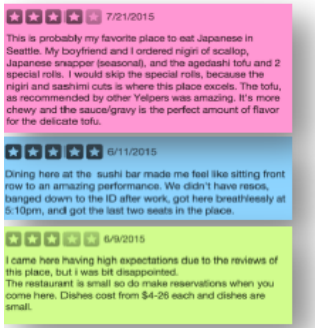
Classification

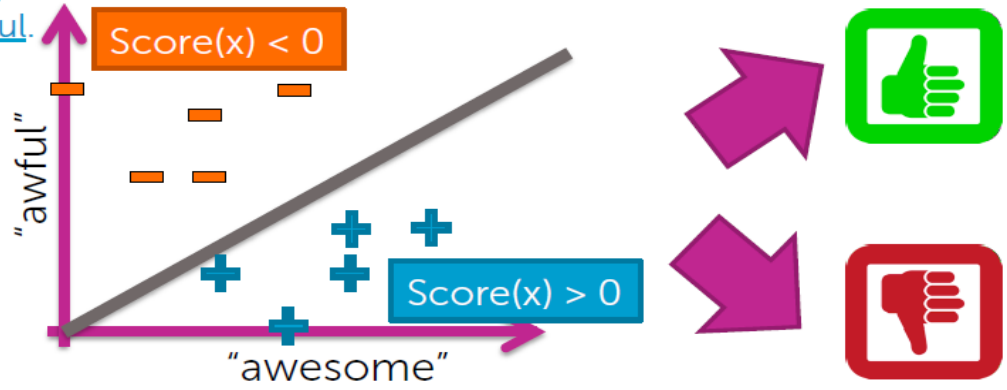
Case study: Score of the restaurant



Sushi was awesome,
the food was awesome,
but the service was awful.

All reviews:





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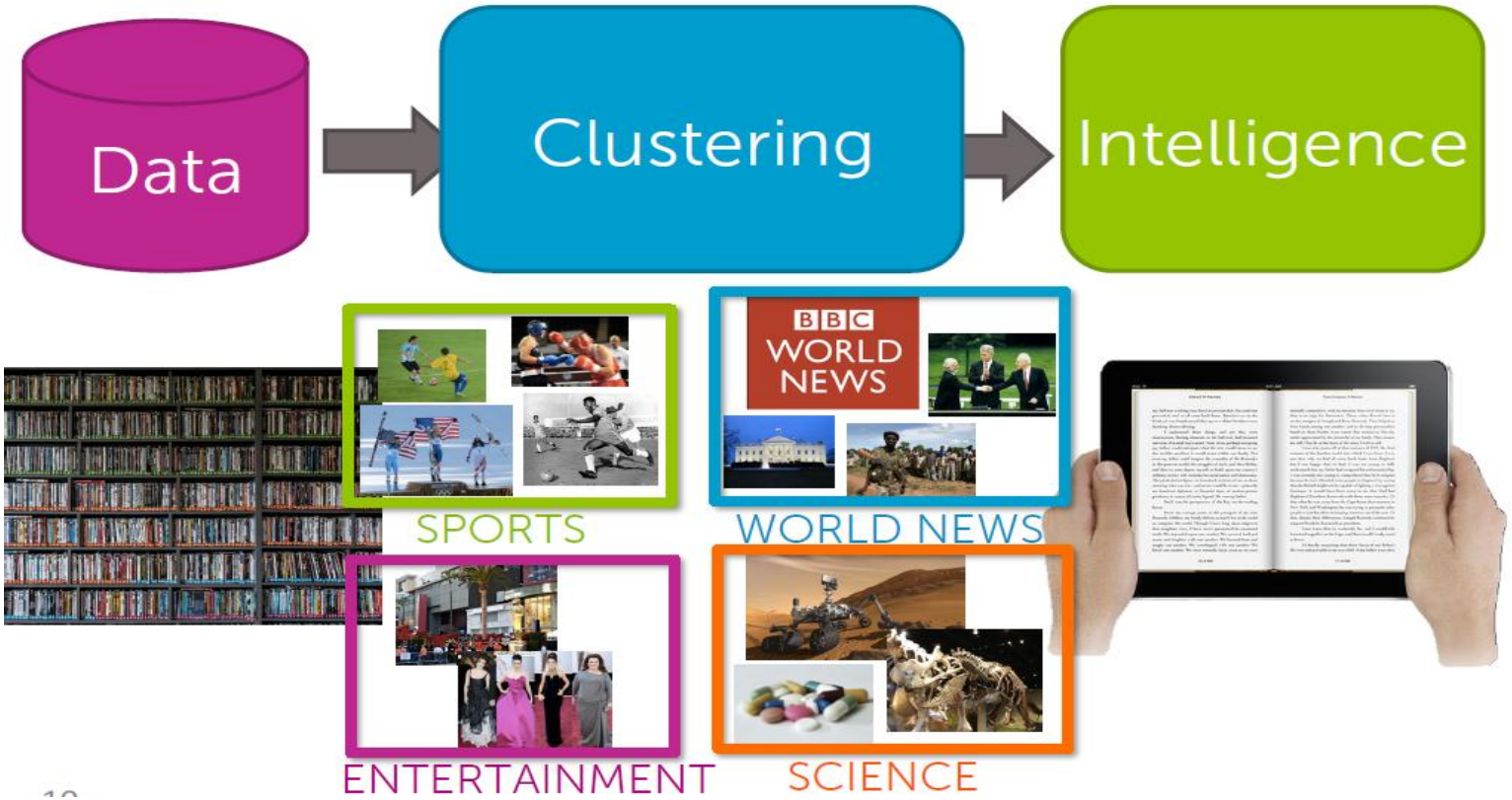
Clustering

Case study: assigning books to groups by topics



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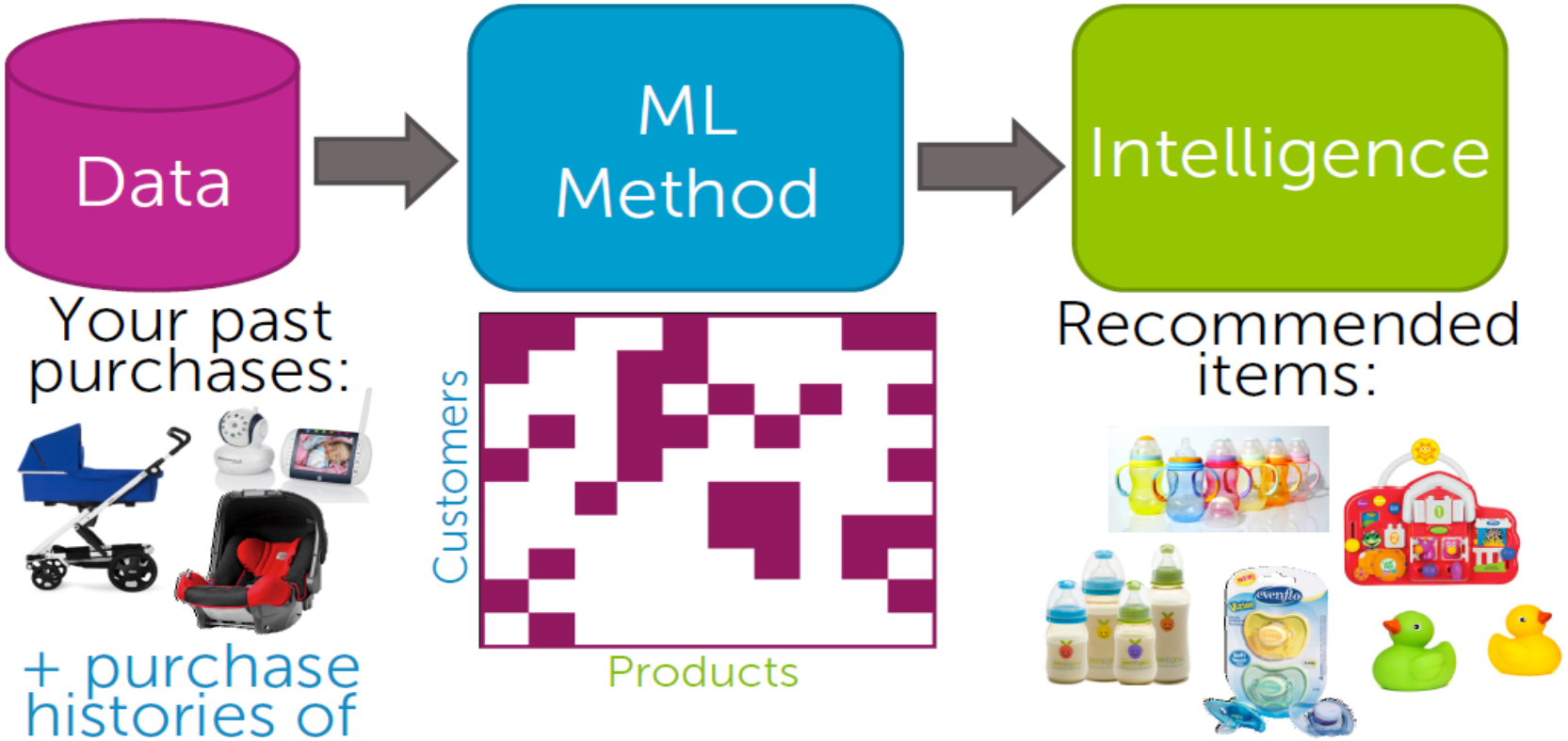
Recommendation

Case study: personalisation of recommending items



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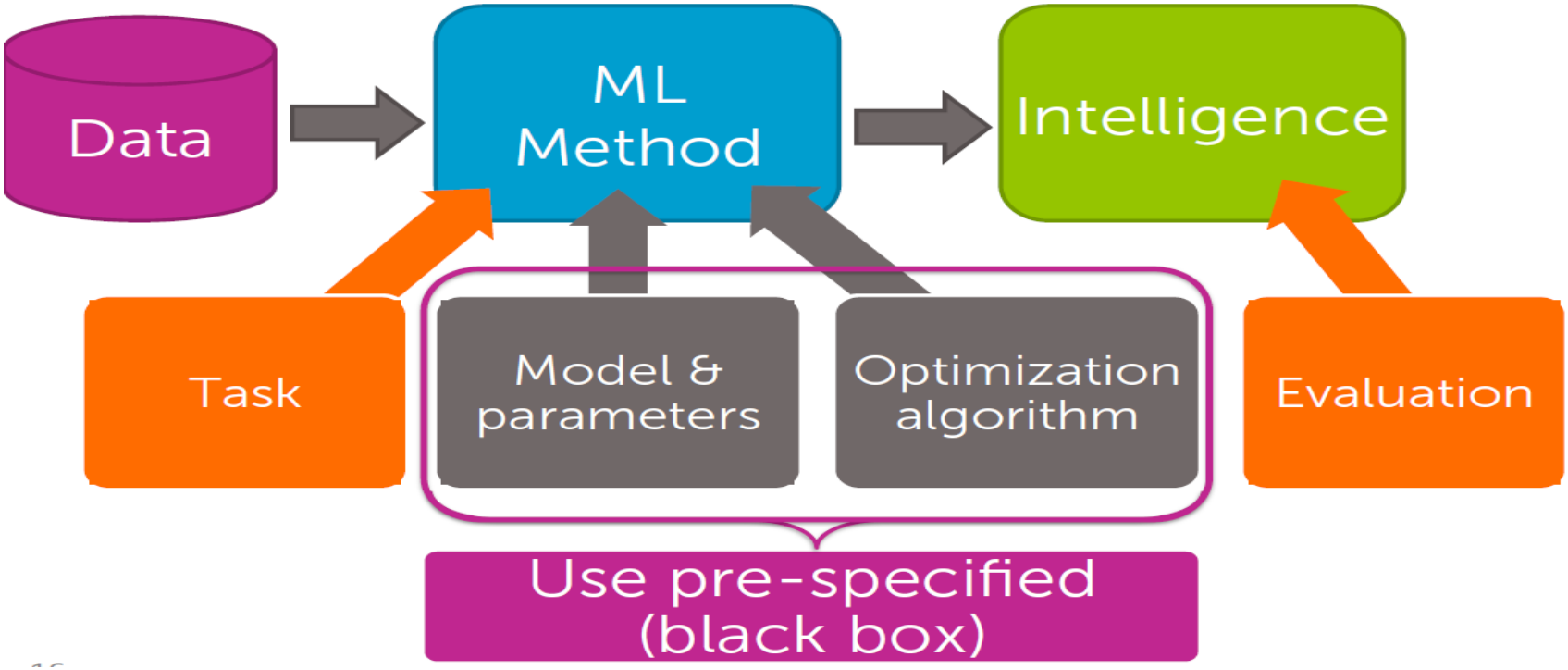
Deploying inteligence module

Case studied are about building, evaluating, deploying inteligence in data analysis.



Regression: Predicting house prices

Models

- Linear regression
- Regularization: Ridge (L2), Lasso (L1)

Algorithms

- Gradient descent
- Coordinate descent

Concepts

- Loss functions, bias-variance tradeoff, cross-validation, sparsity, overfitting, model selection

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Classification: Sentiment analysis

Models

- Linear classifiers (logistic regression, SVMs, perceptron)
- Kernels
- Decision trees

Algorithms

- Stochastic gradient descent
- Boosting

Concepts

- Decision boundaries, MLE, ensemble methods, random forests, CART, online learning

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Clustering: Finding documents

Models

- Nearest neighbors
- Clustering, mixtures of Gaussians
- Latent Dirichlet allocation (LDA)

Algorithms

- KD-trees, locality-sensitive hashing (LSH)
- K-means
- Expectation-maximization (EM)

Concepts

- Distance metrics, approximation algorithms, hashing, sampling algorithms, scaling up with map-reduce

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Getting your ETCs for the lectures

- **I foresee a written exam on the theory part.**
- **List of topical questions will be available before Xmass break.**
- **You will be asked to answer 5 questions out of 25-30 on the list.**