Machine Learning Algorithms for Optical Fiber Telecoms

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Personal background

- **Bangor University, Wales, UK** (PhD)
  - Optical transmission for >40-Gb/s local and access networks
- **Athens Information Technology centre, Athens, Greece**
  - Passive optical networks (PONs)
- **Telecom Paris-Tech, France (collaboration with France Telecom-Orange Labs)**
  - Coherent optical communications for >100-Gb/s multi-channels
- **Aston University, UK**
  - Digital signal processing (DSP)-based fibre nonlinearity compensation
- **University of Sydney, Sydney, Australia**
  - Machine learning DSP for optical commun. and photonic-chip applications
- **Dublin City University (DCU), Ireland (visiting researcher at Xilinx-Ireland)**
  - Real-time machine learning DSP for optical communications

DCU

XILINX

EPIC
Energy-efficient Phase-Insensitive Coherent communications

Machine learning for optical communications

Machine Learning

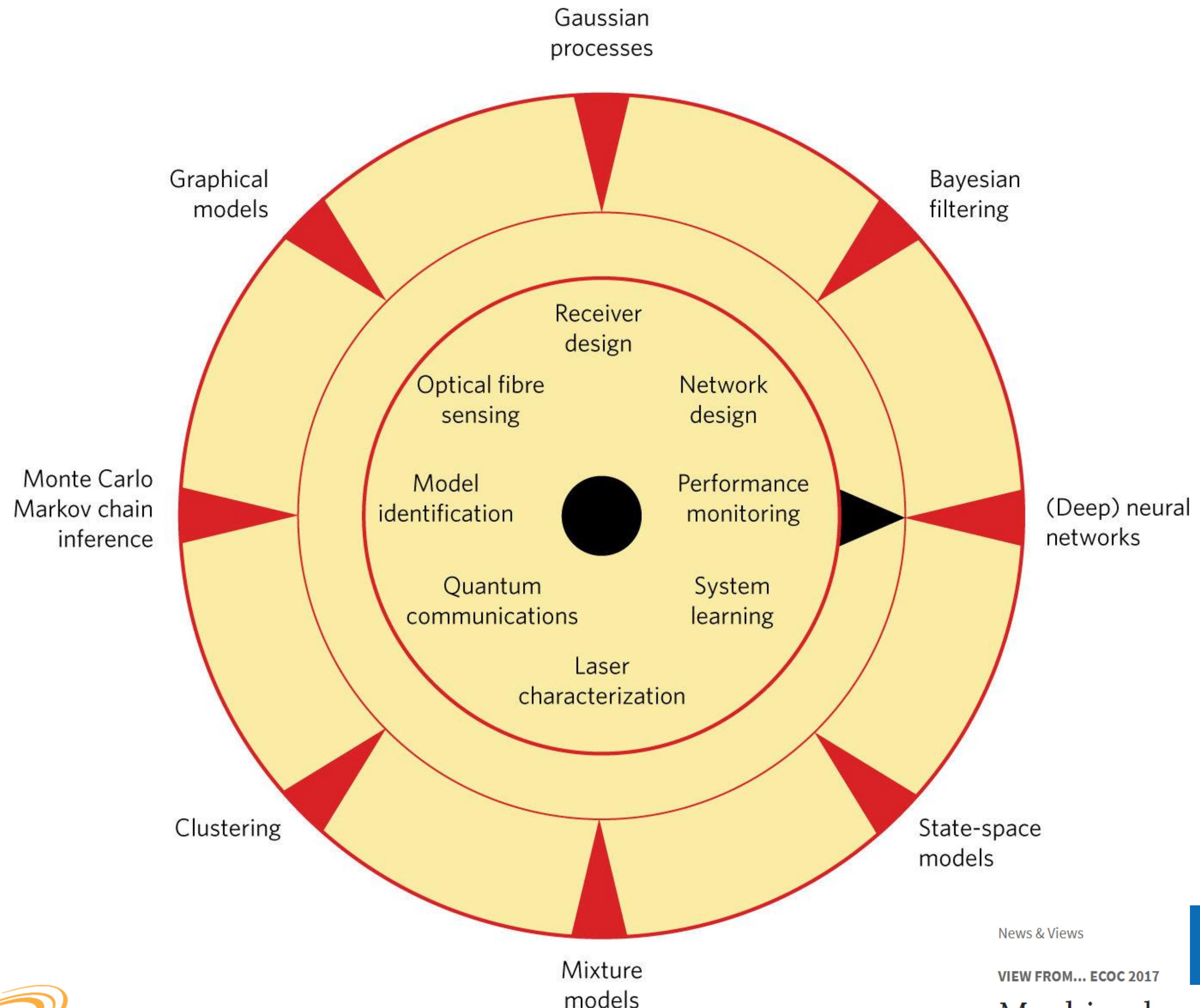
- DET, KDE, GMM
- PCA, ICA
- IS, MCMC
- HMM (EKF, UKF, PF)
- ANN (MLP, HNN, RBM, CNN, RNN)
- SVM (kernel: polynomial, RBF, sigmoid)
- Deep learning (DBN, etc.)

Apply

Optical Communications

- Linearity: CD, PMD
- Nonlinearity: SPM, XPM, XPolM, FWM
- Nonlinear equalization
- Polarization recovery
- Carrier phase recovery
- Nonlinear capacity analysis
- Coded-modulation design

Photonics: machine learning under the spotlight



News & Views

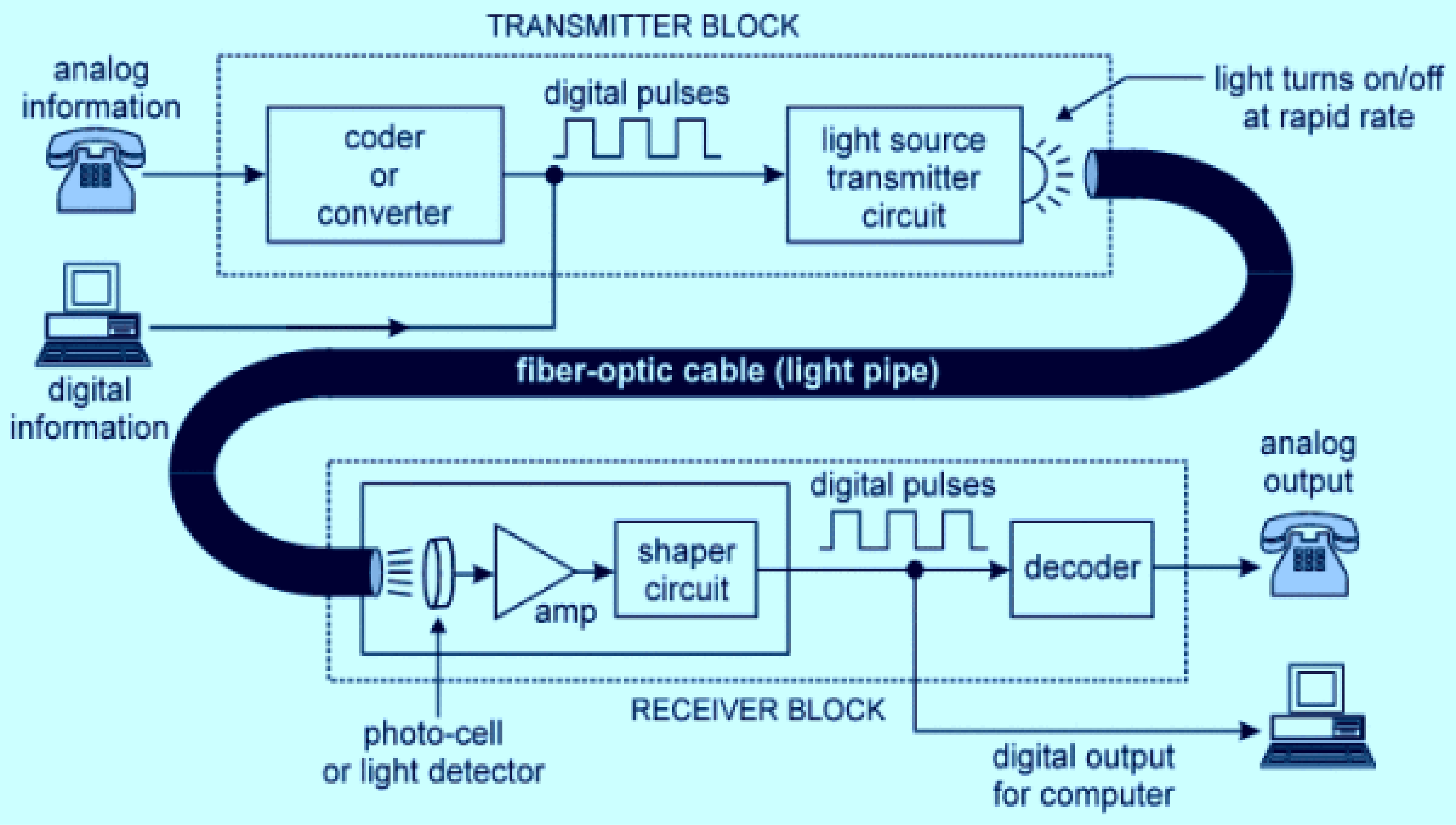
nature photonics

VIEW FROM... ECOC 2017

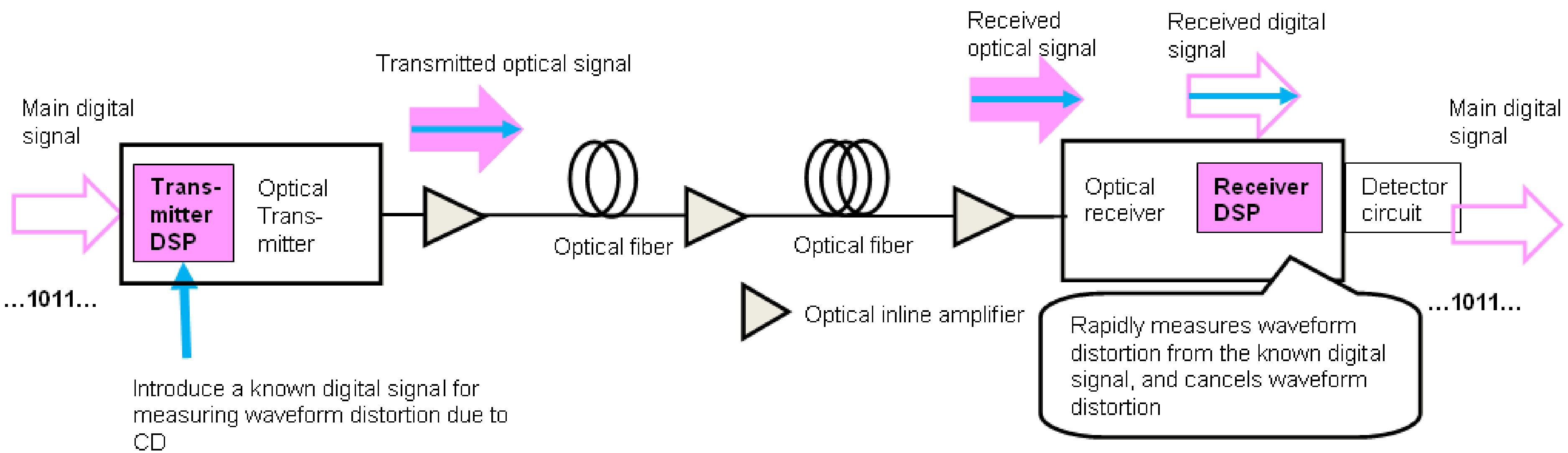
Machine learning under the spotlight

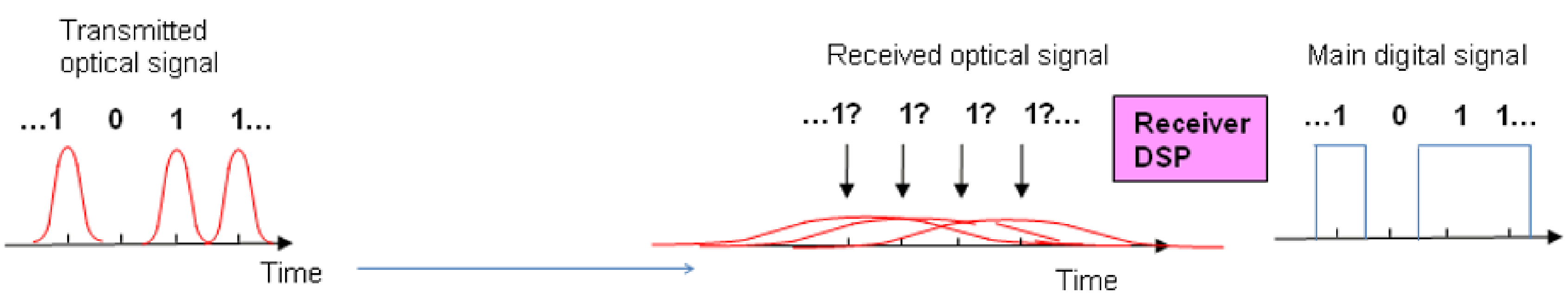
Darko Zibar, Henk Wymeersch & Ilya Lyubomirsky

Typical optical communication system

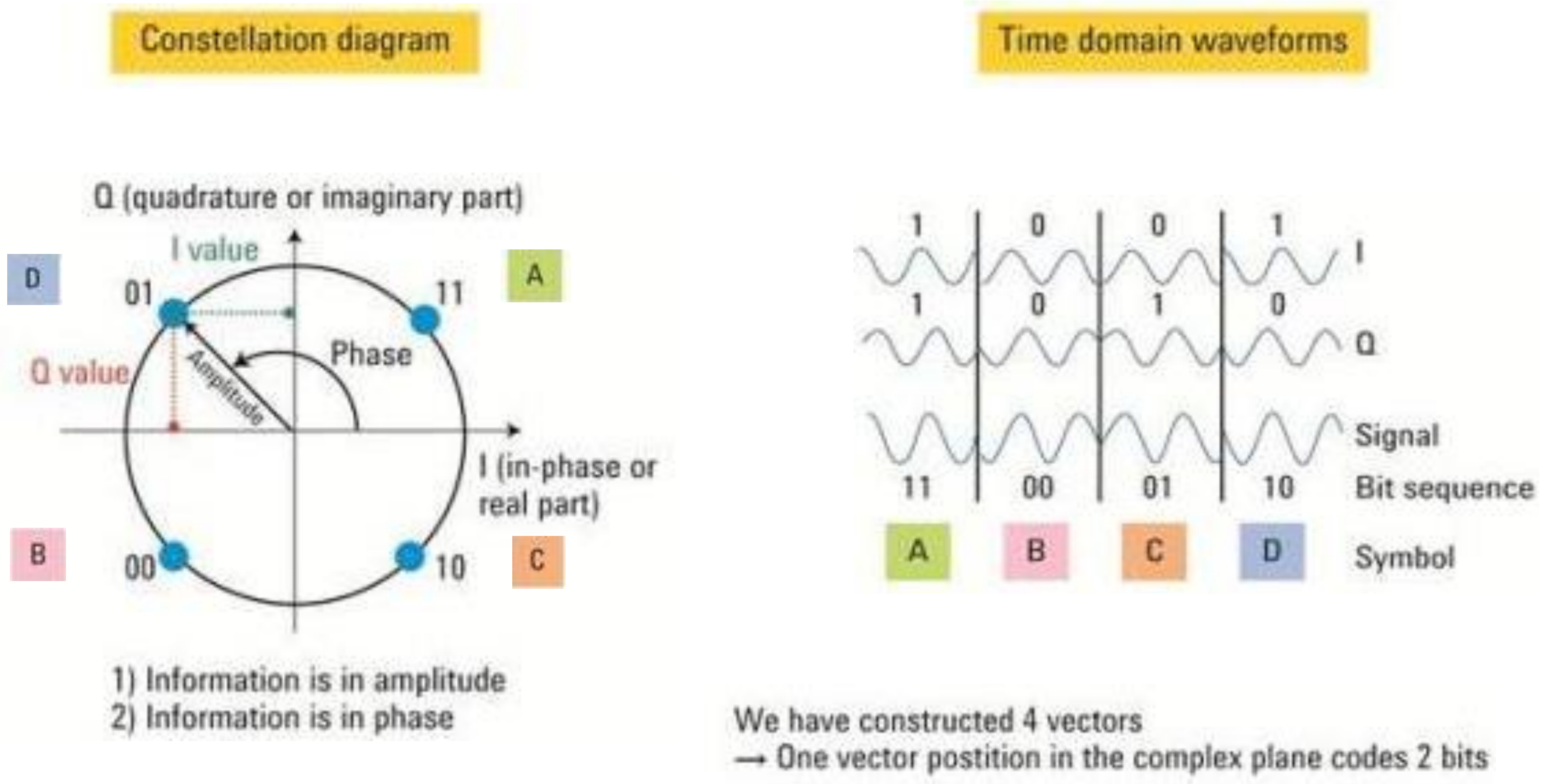


DSP importance in optical communications





Constellation diagrams for modulation



DSP receiver design with machine learning

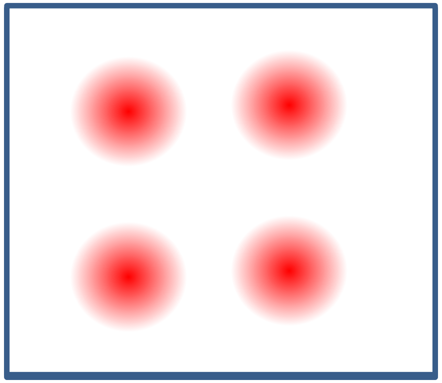
- **DSP Receiver processing:**

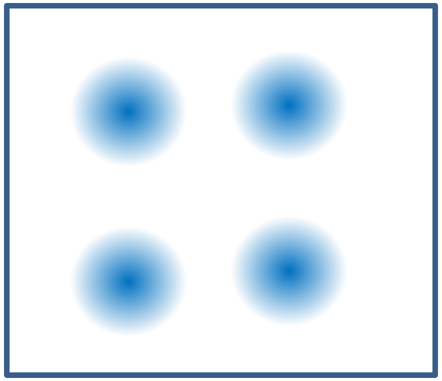
Synchronization

Optical carrier frequency offset compensation

Linear Equalization & Machine Learning

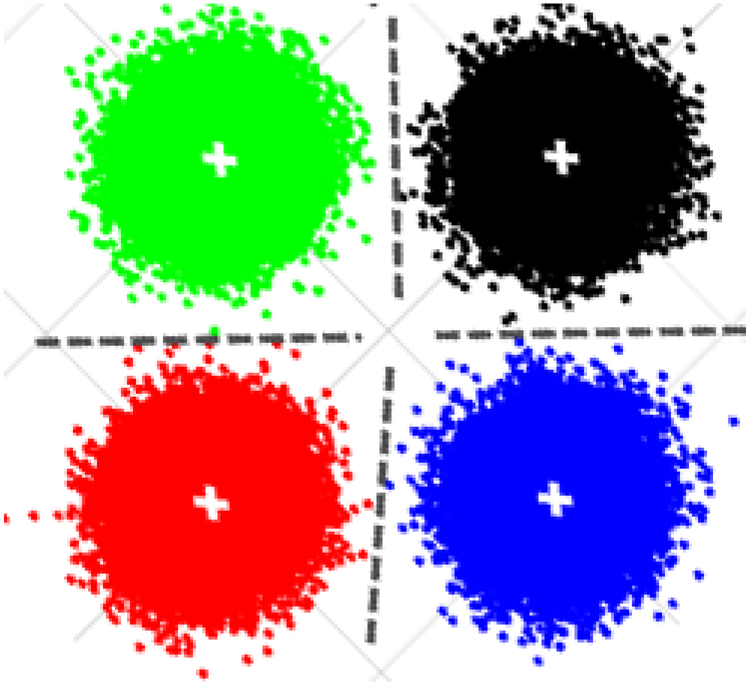
Data Recovery



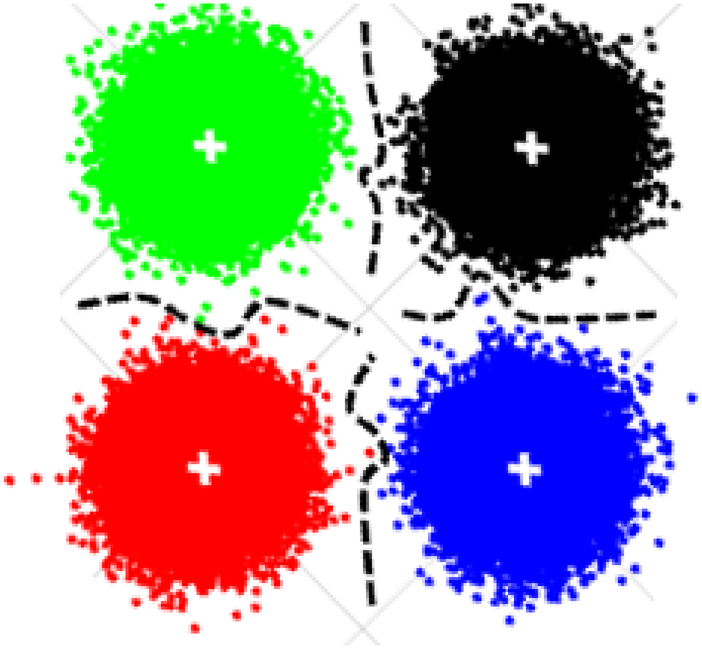


Clustering-based machine learning

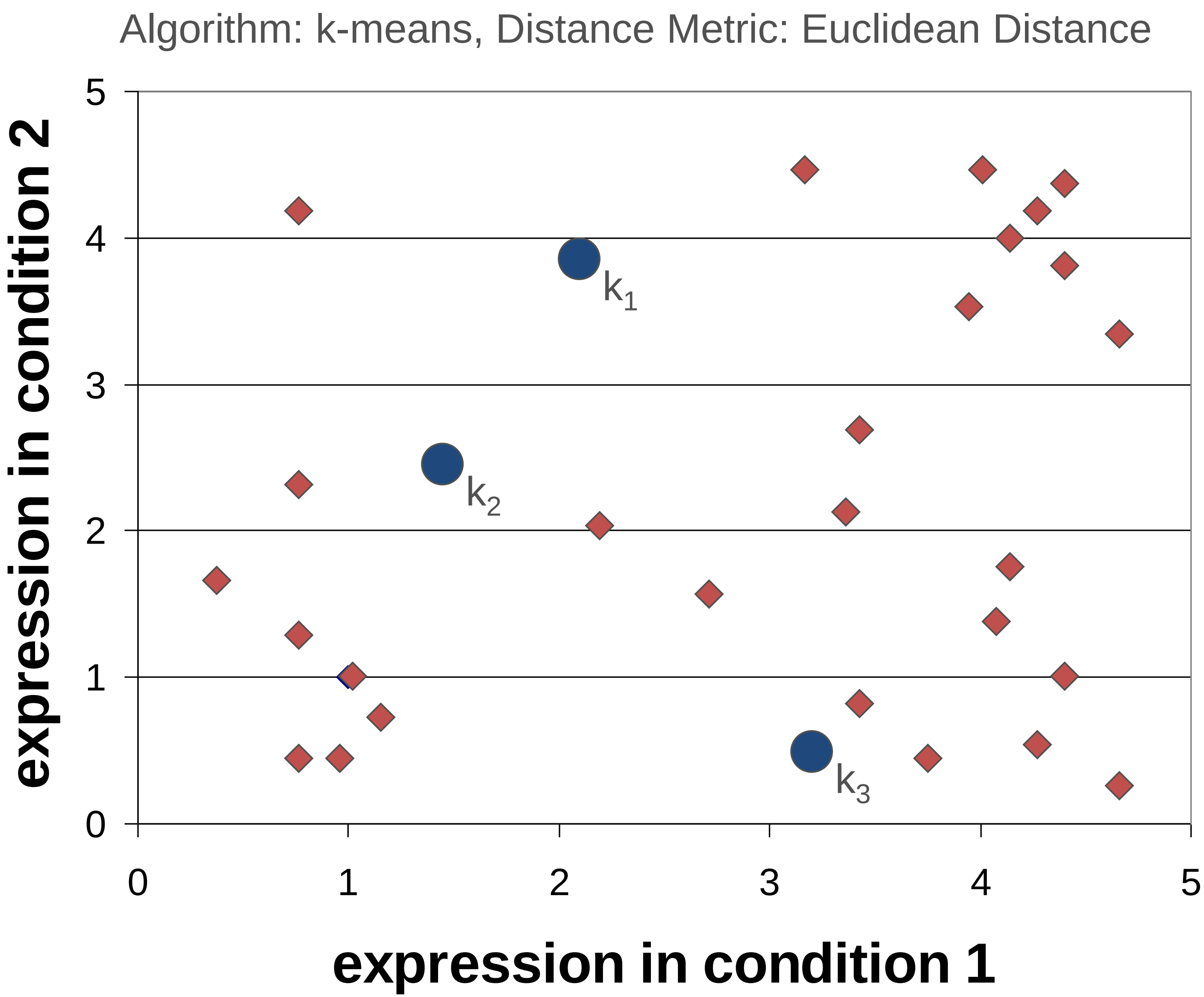
K-means



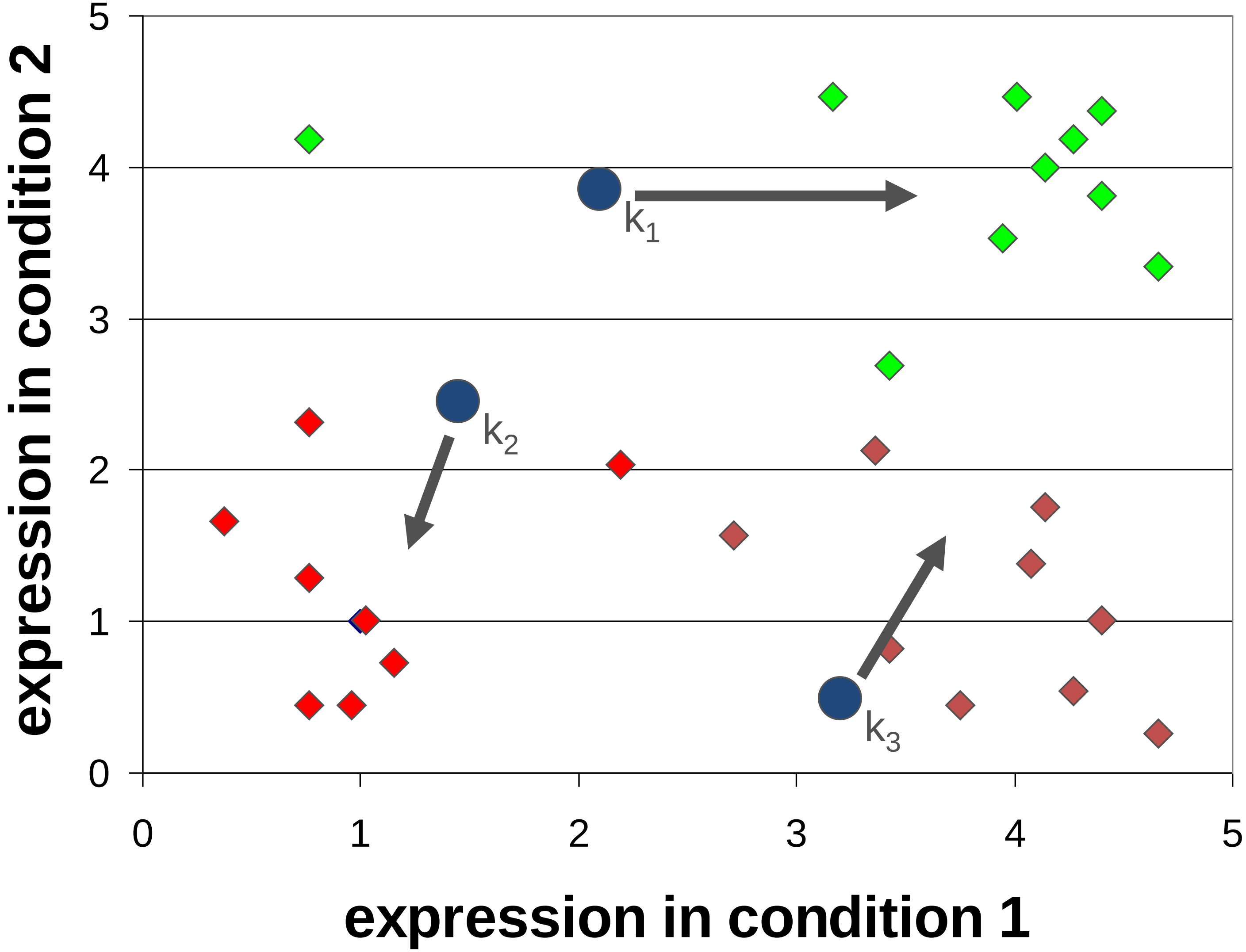
Fuzzy-logic c-means



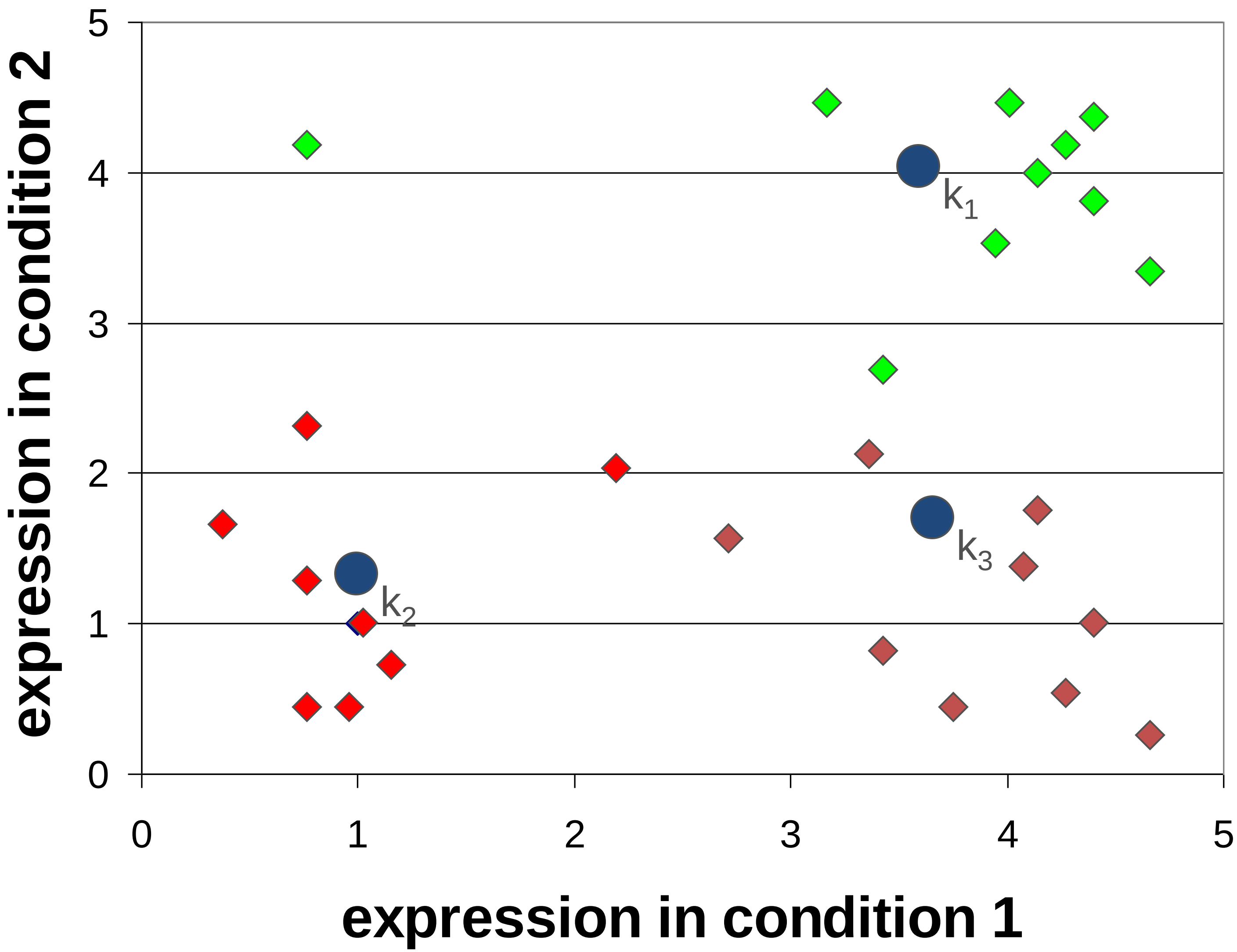
K-means: Step 1



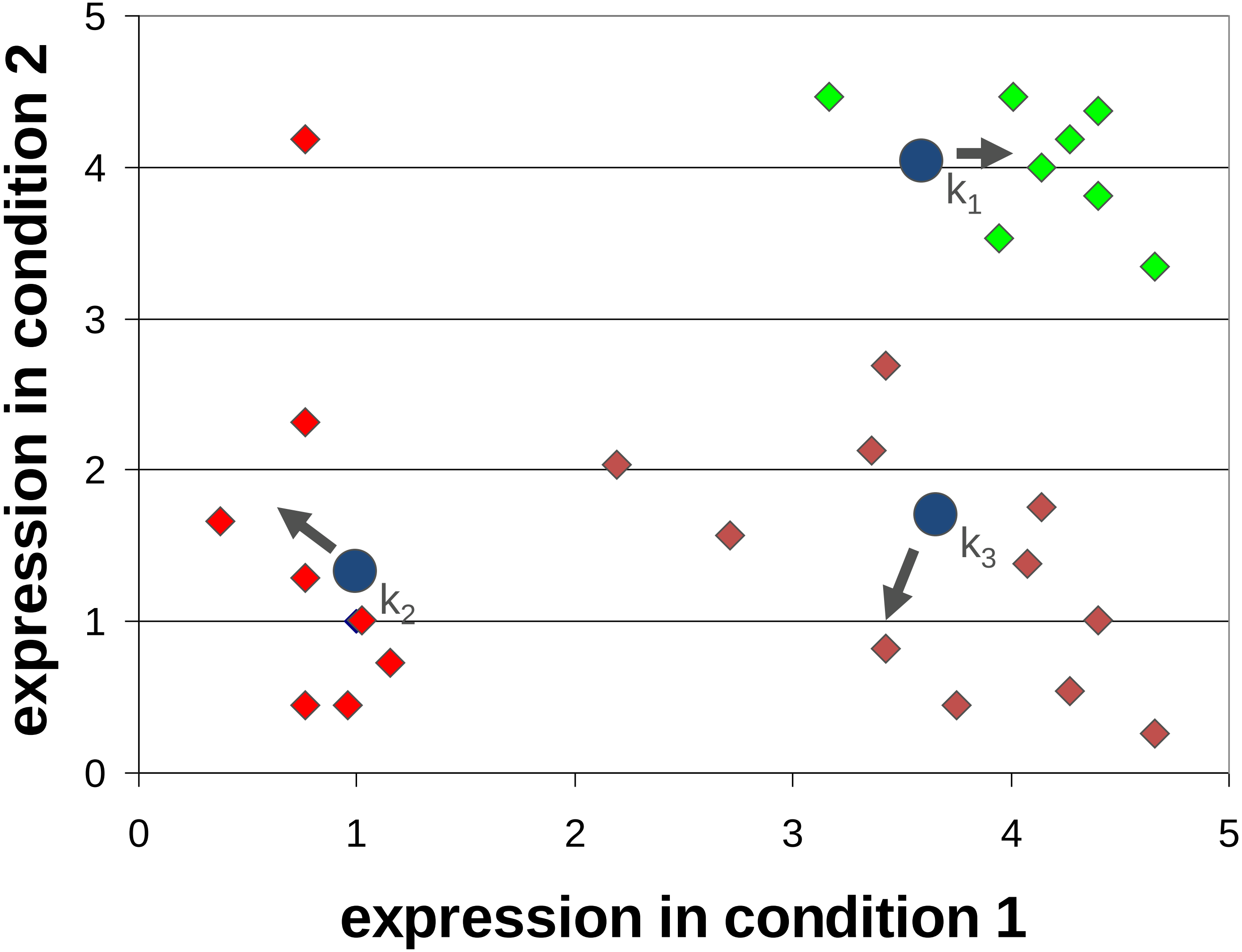
K-means: Step 2



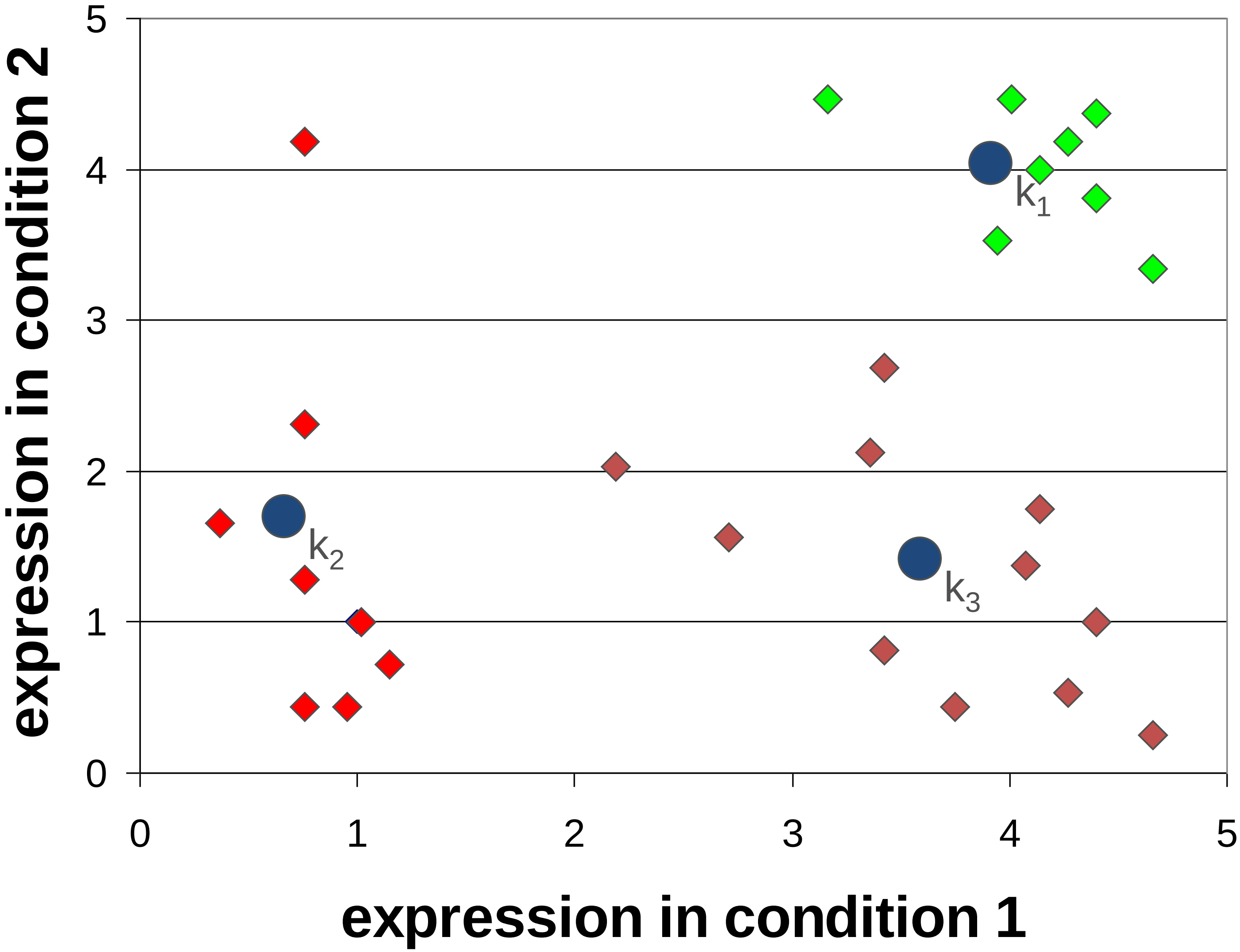
K-means: Step 3



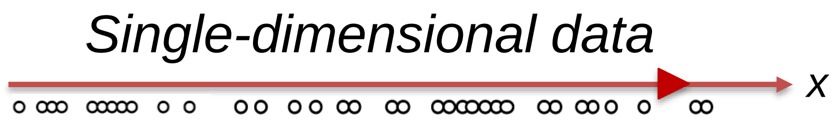
K-means: Step 4



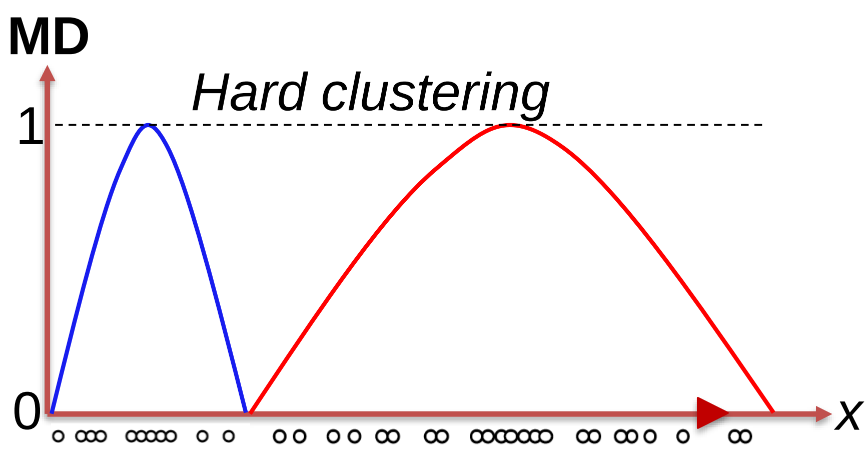
K-means: Step 5

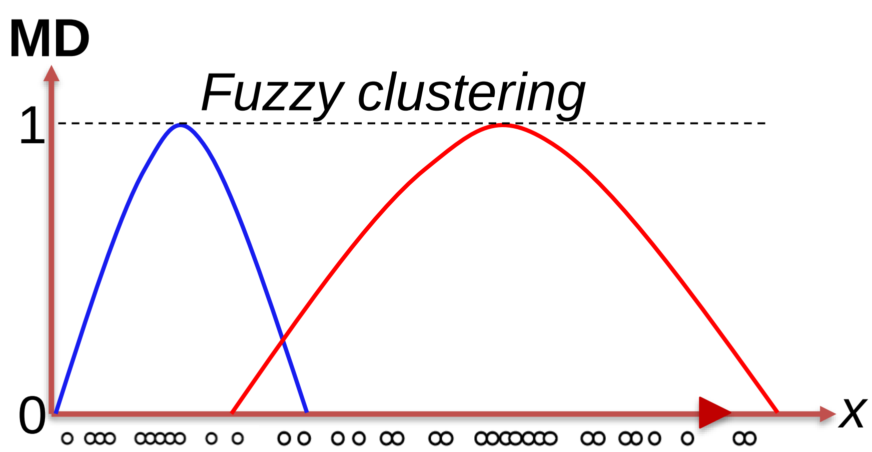


Fuzzy-logic c-means



MD: Membership Degree





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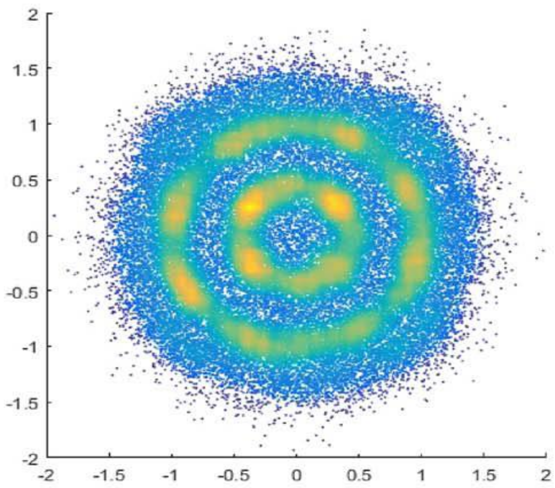
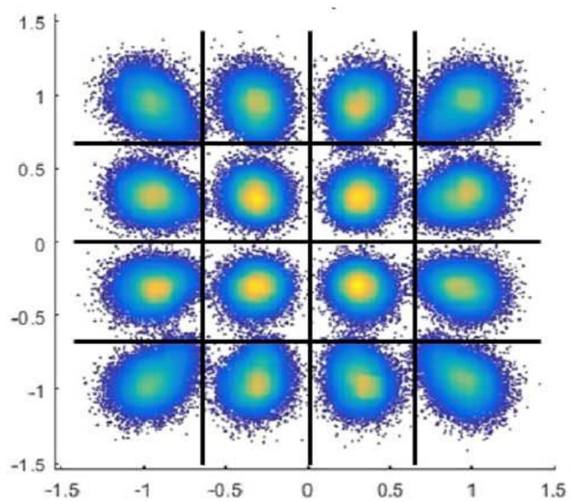
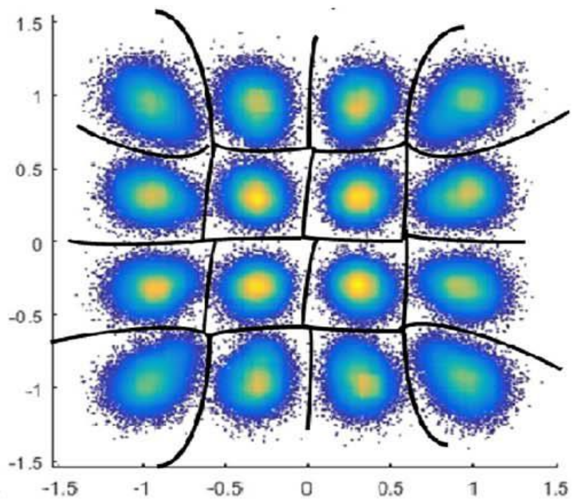
Received constellation diagrams for 16-QAM



No equalization



Linear equalization - hard decision boundaries

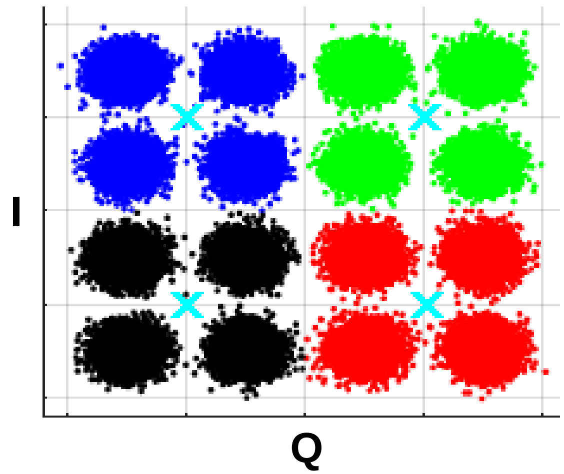


Machine learning - soft decision/nonlinear boundaries

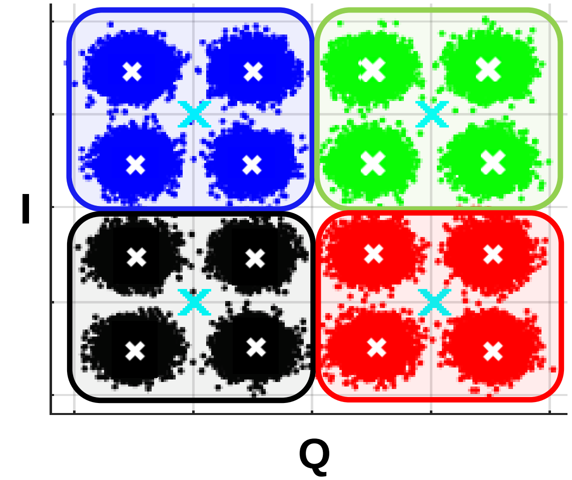
Alternative design for 16 clusters

CASE-1

Step 1: large group of 4 clusters

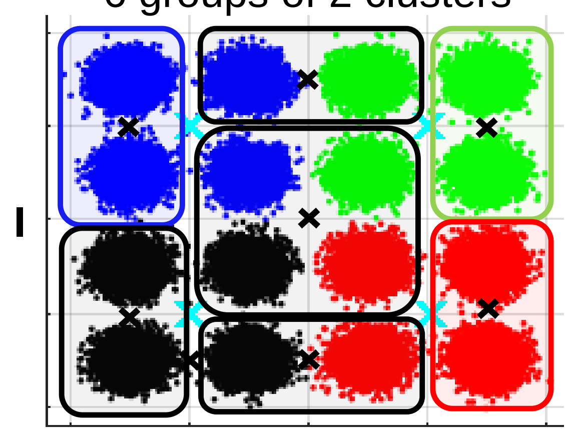


Step 2: 4 groups of 4 clusters

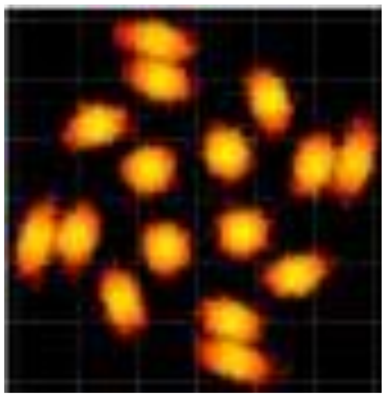


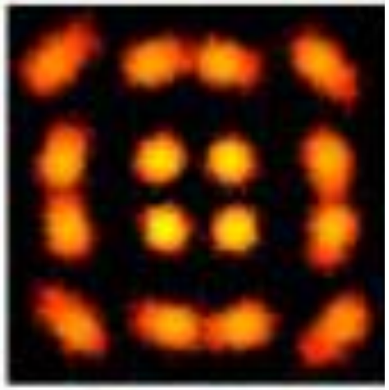
CASE-2

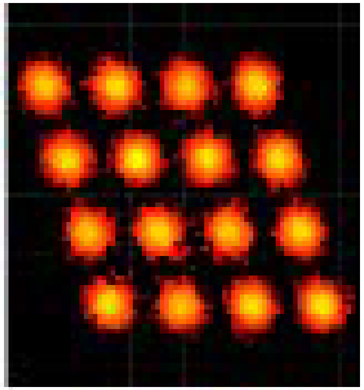
Single-step: 1 group of 4 clusters & 6 groups of 2 clusters

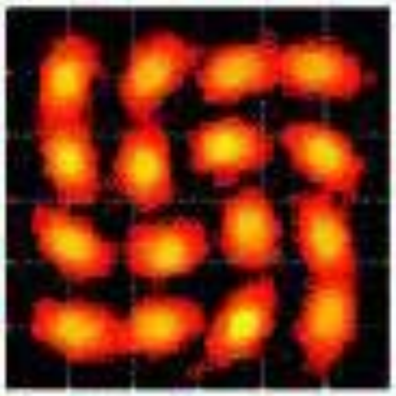


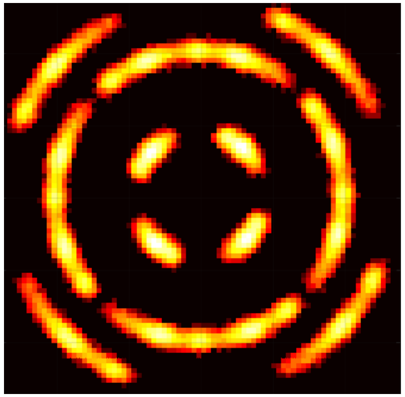
Shapes of constellation diagrams



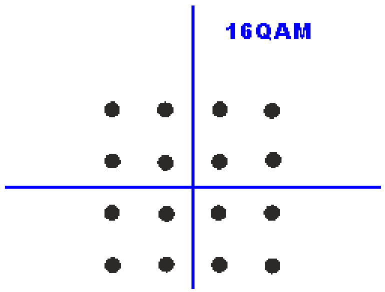




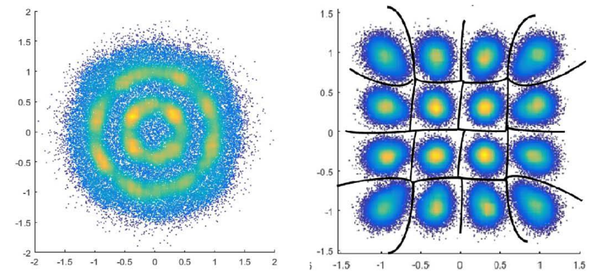




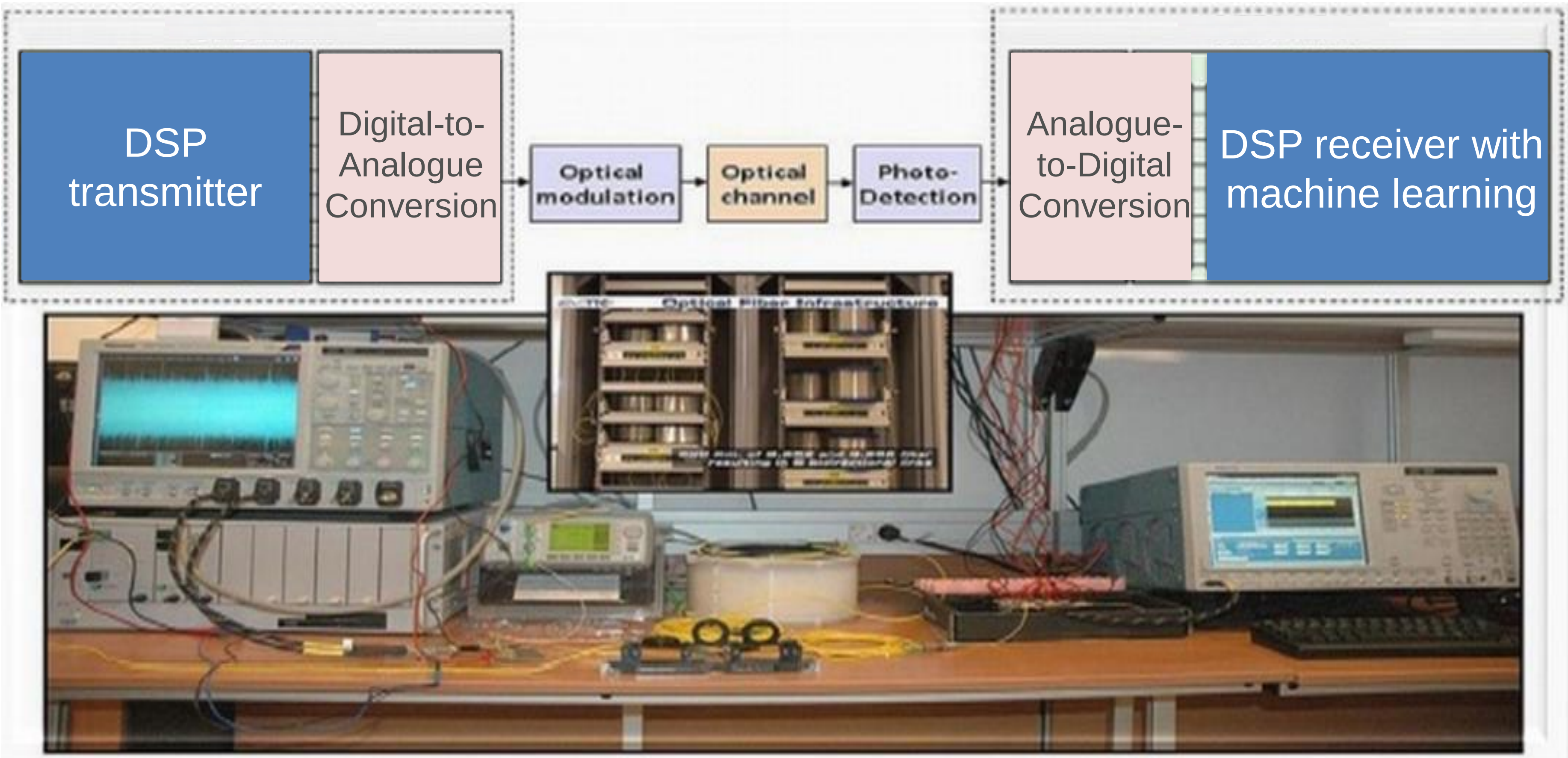
Transceiver setup



MATLAB Electrical Transmitter

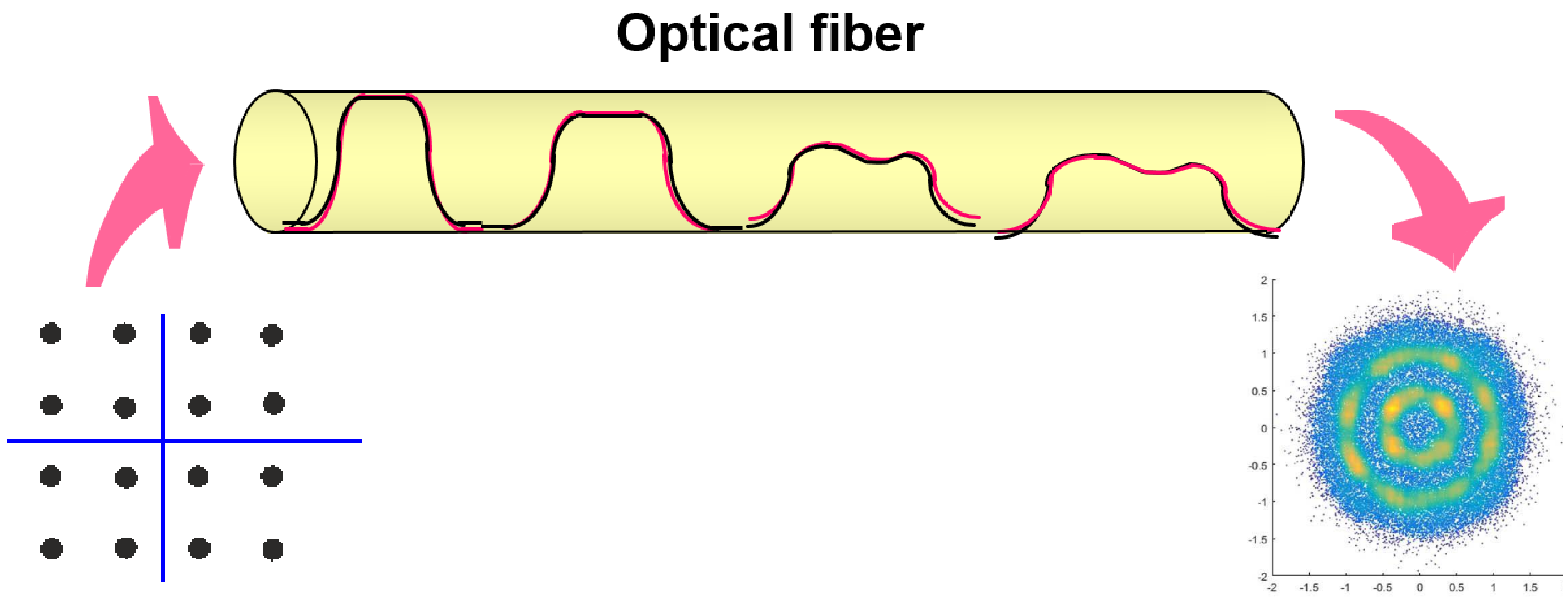


MATLAB Electrical Receiver



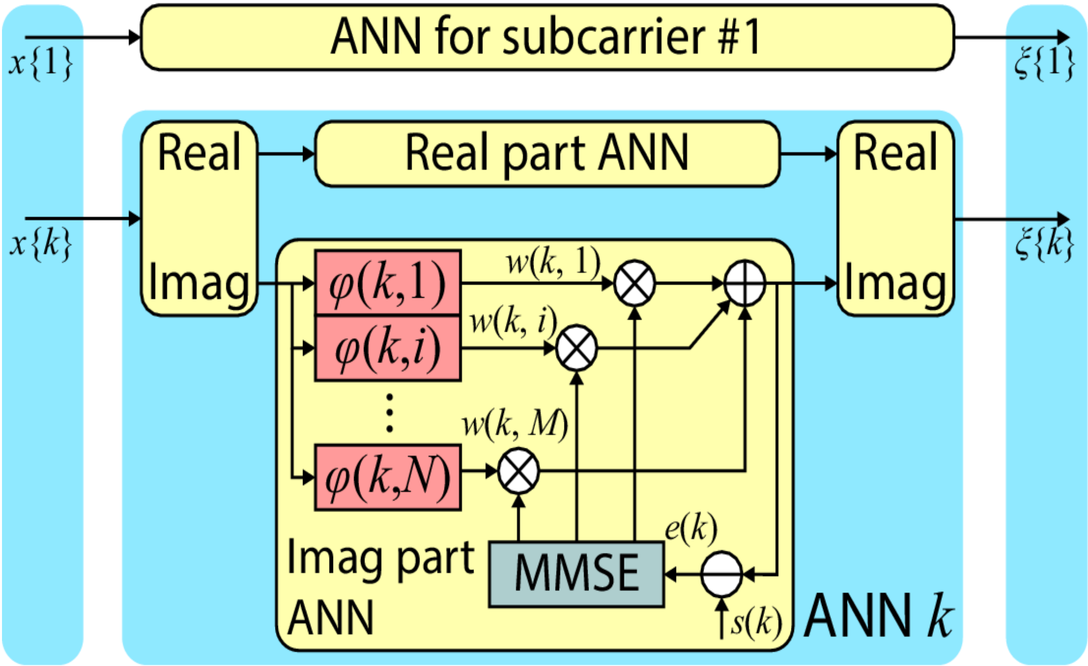
Nonlinear distortion

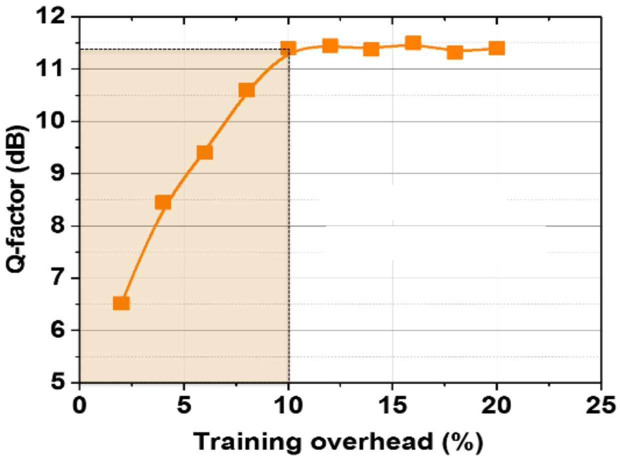
High power intensity ⇨ **Refractive index change** ⇨ **Frequency chirp** ⇨ **Spectrum broadening** ⇨ **Waveform distortion due to chromatic dispersion**



Artificial Neural Network design

- **ANN: Artificial Neural Network**



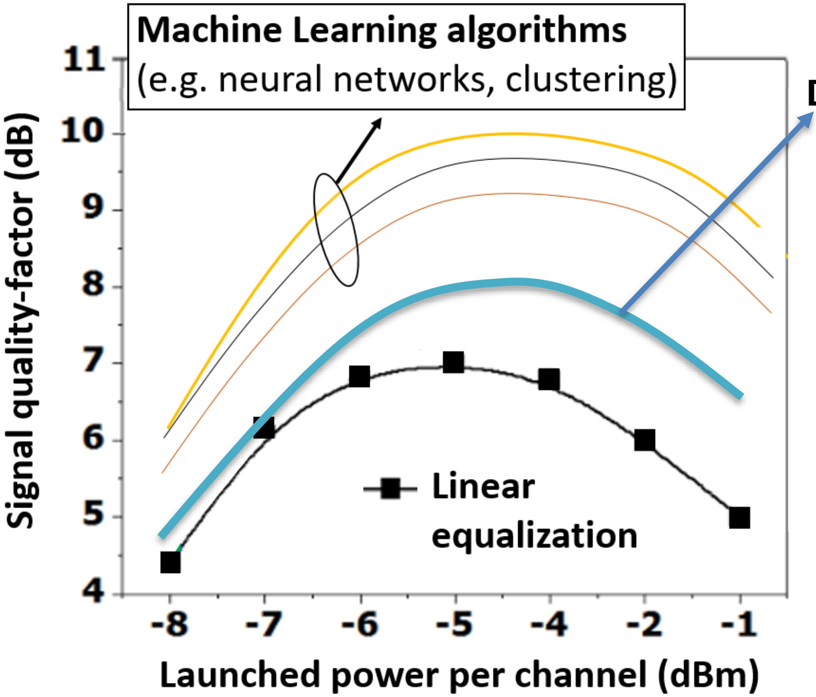


$\varphi_{k,i}(x)$ = nonlinear transformations of subcarrier k
N = level of constellation mapping
w = weights
e = error
s = signal
MMSE = minimum-mean square-error

$$\mathrm{e(k) = s(k) - \hat{s}(k)}$$

$$\hat{s}(k) = \sum_{i=1}^{N} w_{k,i}\varphi_{k,i}(s(k))$$

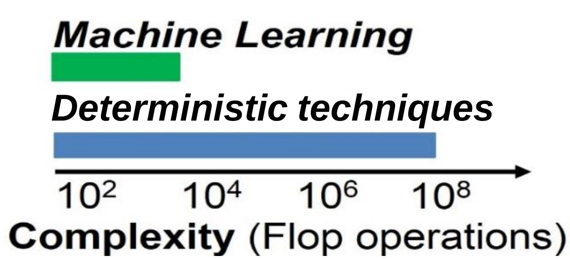
Why machine learning is good for us?



- Machine Learning tackles stochastic noises in optical networks without knowledge of the fibre link parameters (*versatile learning*).
- It has benefit over wireless systems because optical link has stable parameters.

[1] E. Giacoumidis et al, OSA Opt. Let. 12 , 123 (2016)
[2] E. Giacoumidis et al, IEEE JLT 10, 234 (2017)

Complexity comparison (Number of operations)



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Comparison with benchmark technologies

Nonlinear compensation techniques:

- Digital back propagation (DBP)
- Optical phase conjugation (OPC)
- Phase conjugated twin wave (PC-TW)

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Phase-conjugated twin waves for communication beyond the Kerr nonlinearity limit

Xiang Liu*, A. R. Chraplyvy, P. J. Winzer, R. W. Tkach and S. Chandrasekhar

	DBP	OPC	PC-TW	Proposed
Performance	✓	✓	✓	✓
Complexity	☹	😐	✓	✓
WDM links	😐	✓	✓	✓
Links with ROADM	😐	☹	😐	✓
Overhead	✓	✓	☹	✓
Flexibility	✓	☹	✓	✓

✓ Advantage   😐 Limited benefit   ☹ Challenge

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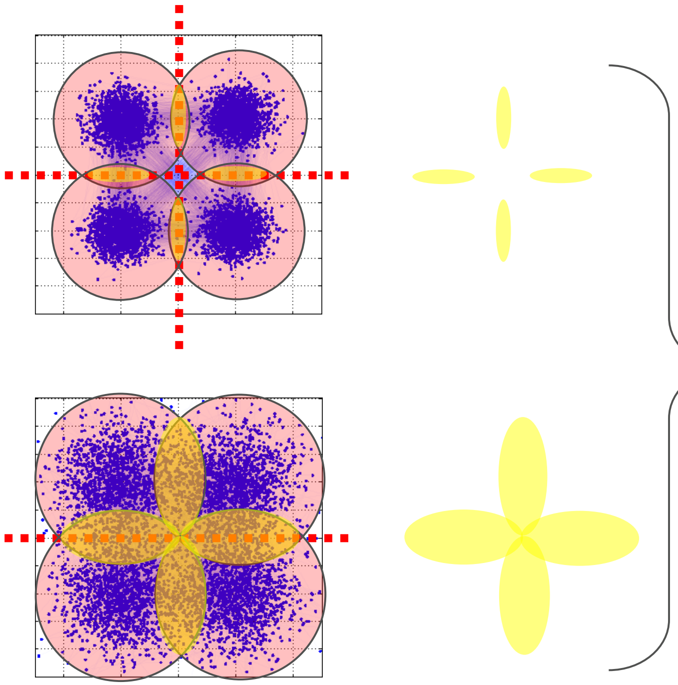
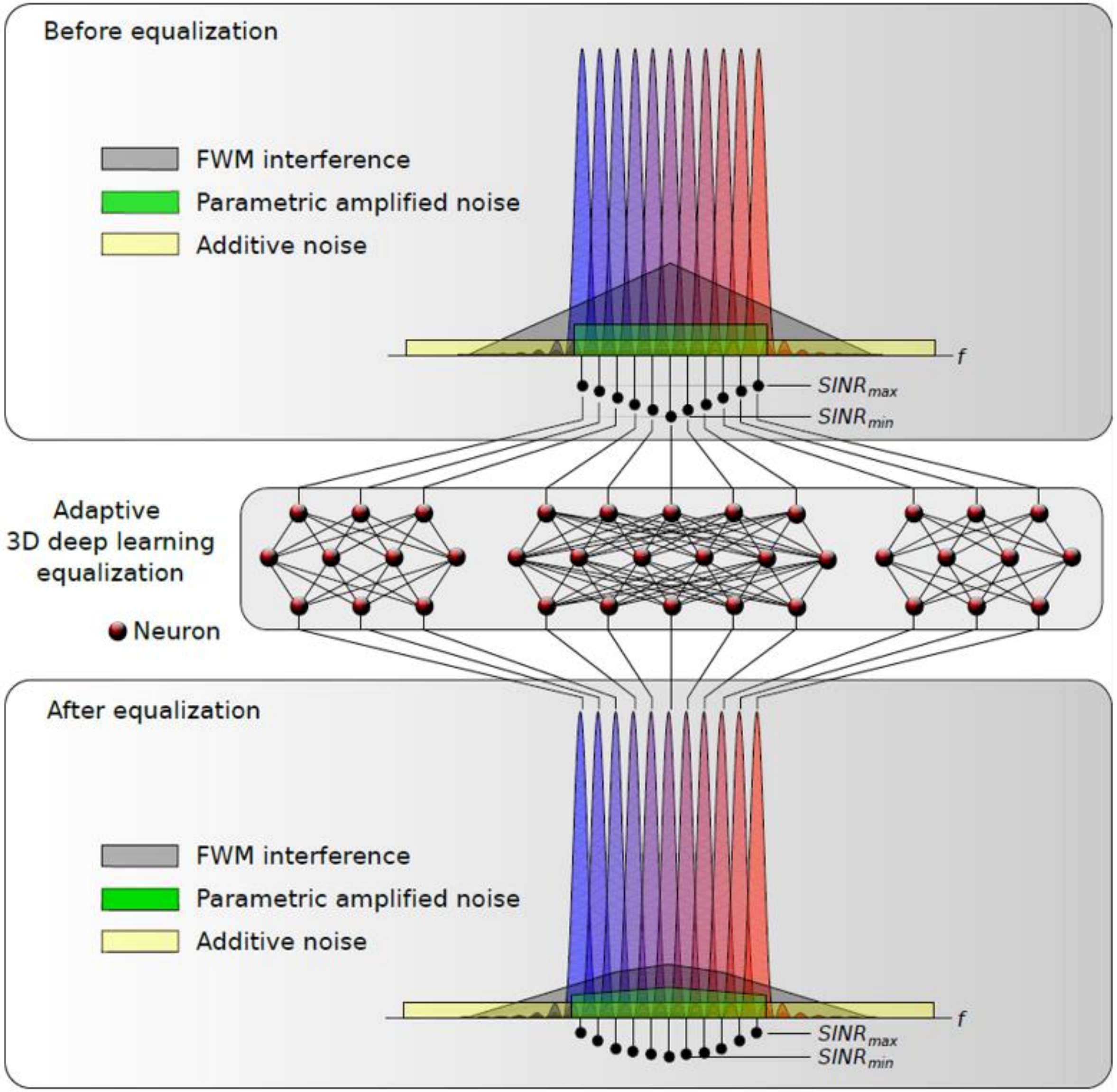
Crucial points

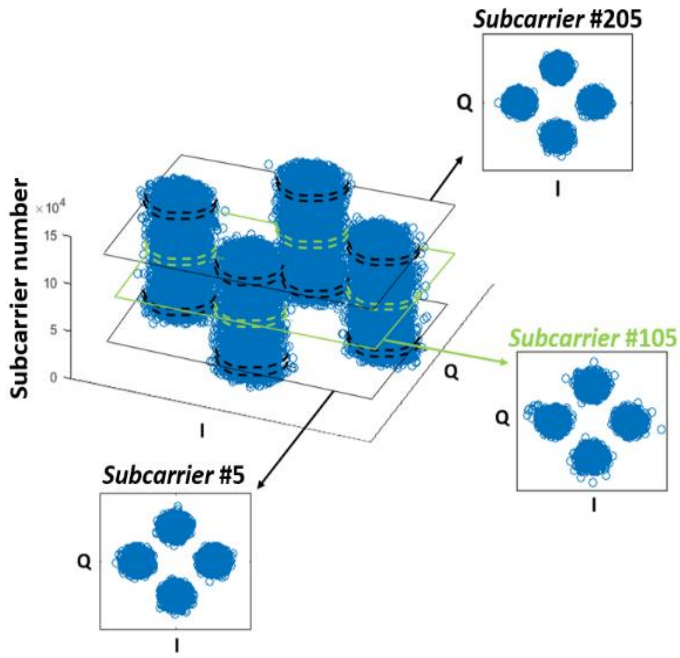
Real-time signal processing on FPGA



areas where errors
are most likely

3D deep learning?





Thank you for your attention !!!