1. Physics of imaging
Unconventional imaging and co-design
Part I: Unconventional imaging

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Parts of this course

- Part I : Unconventional imaging
- Part II : Image formation, Mathematical model
- Part III : Image reconstruction methods and examples in Holography
- Part IV : Use of Cramer Rao Lower Bound to co-design a setup

Outline of part I (Unconventional imaging)

1. What is Unconventional imaging ?
2. What physical quantities can be measured ?
3. How are images/data recorded ?
4. Data processing
5. Design of an unconventional imaging system

What is Unconventional imaging ?

Differences between unconventional and conventional imaging.

Conventional imaging :

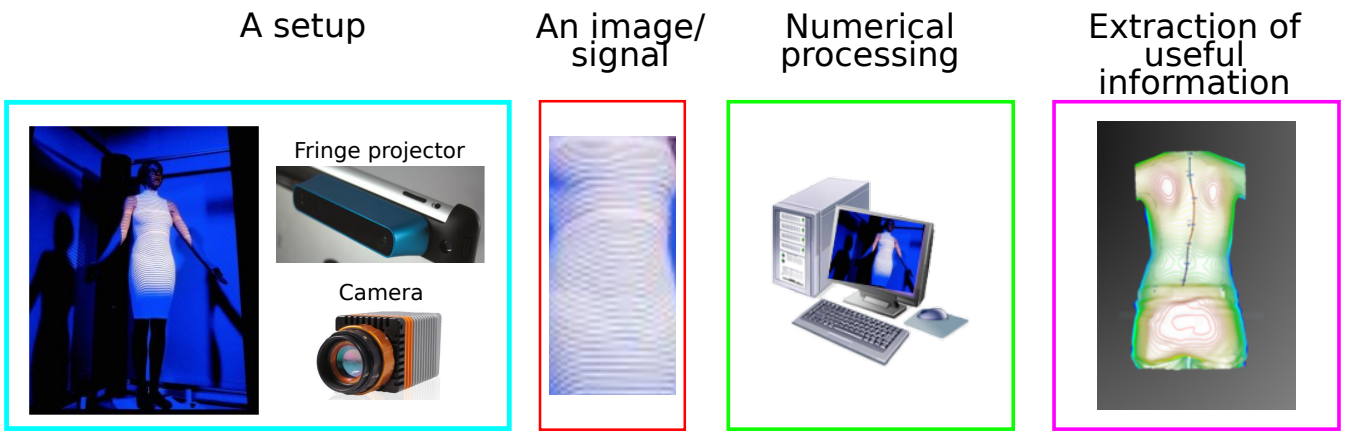
- Images acquired with a classical setup (objective + sensor).
- Image = projection of the 3D scene on a 2D sensor
- Image can be interpreted by human.

Differences between unconventional and conventional imaging.

Unconventional imaging :

- Images acquired with a unconventional setup
- Image = signal that contains richer information.
- Image cannot be interpreted by human.

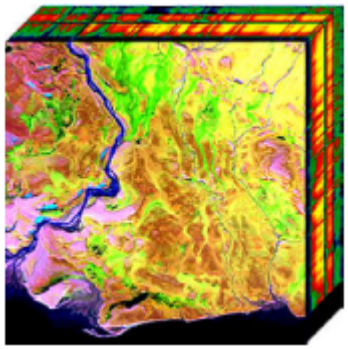
$\Rightarrow$ Numerical processing needed :
Unconventional imaging $\subseteq$ Computational imaging.

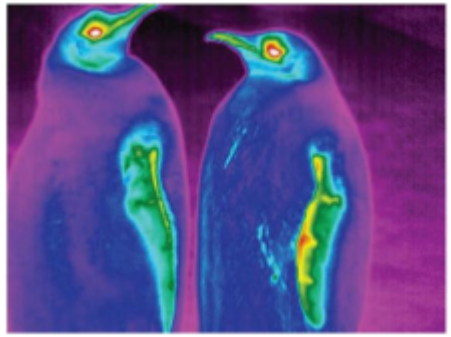
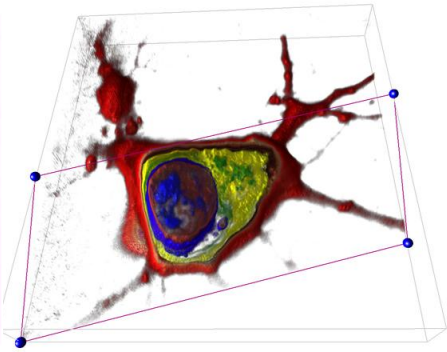


What physical quantities can be measured ?

Strength of unconventional imaging

- Measurements of physical quantities : Depth, humidity, chemical composition, temperature, phase shift (optical thickness, refractive index), ...
- Quantitative imaging.
- Super resolution/Low cost setups...
- Various applications : Biomedical imaging, Chemical engineering, ...

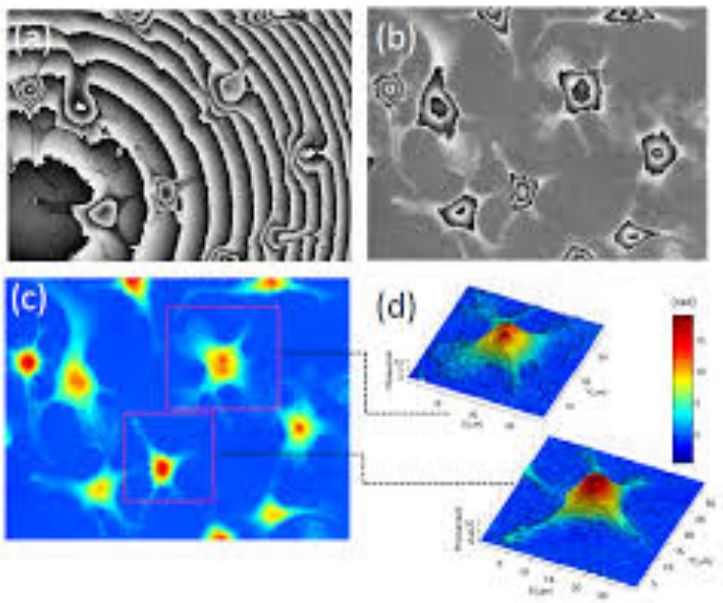


Example : Imaging transparent phase objects

Interferometric setups enable to measure phase shift of objects (here biological cells, microscopy) :

Image / signal processing



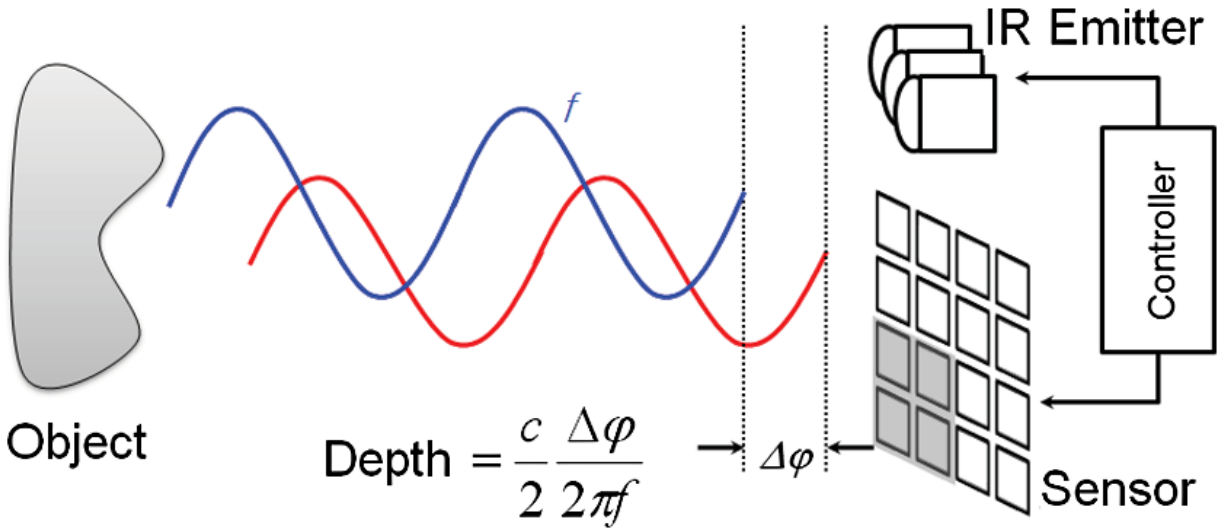
Phase shift/ optical depth estimates

Zuo, Chao, Qian Chen, Weijuan Qu and Anand Asundi. "Phase aberration compensation in digital holographic microscopy based on principal component analysis." Optics letters 38 10 (2013)

How are images/data recorded ?

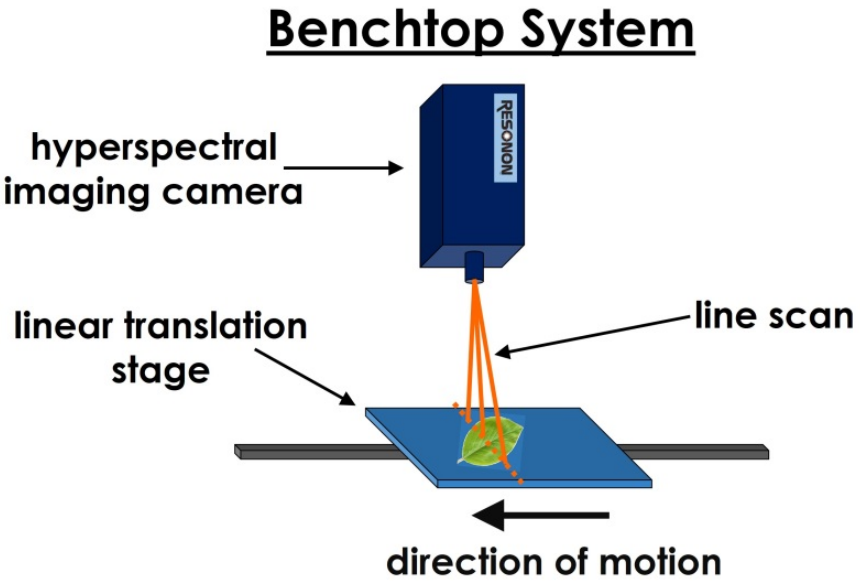
Example 1 : Time Of Flight

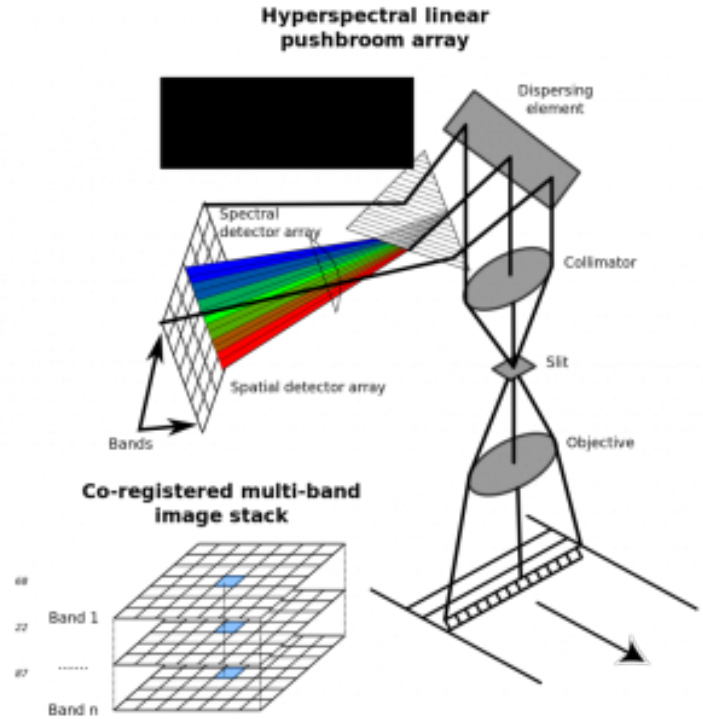
Time Of Flight camera (TOF)



Principle

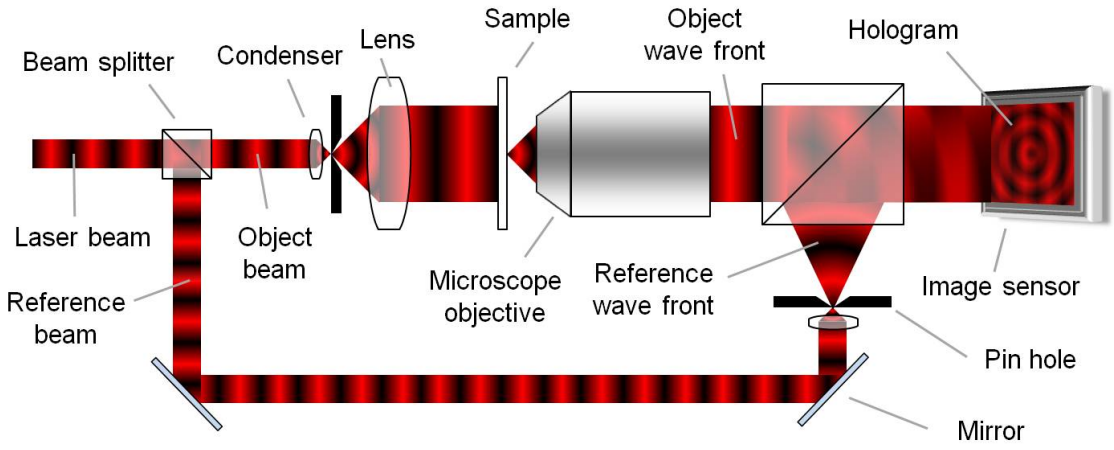
Example 2 : Hyperspectral imaging





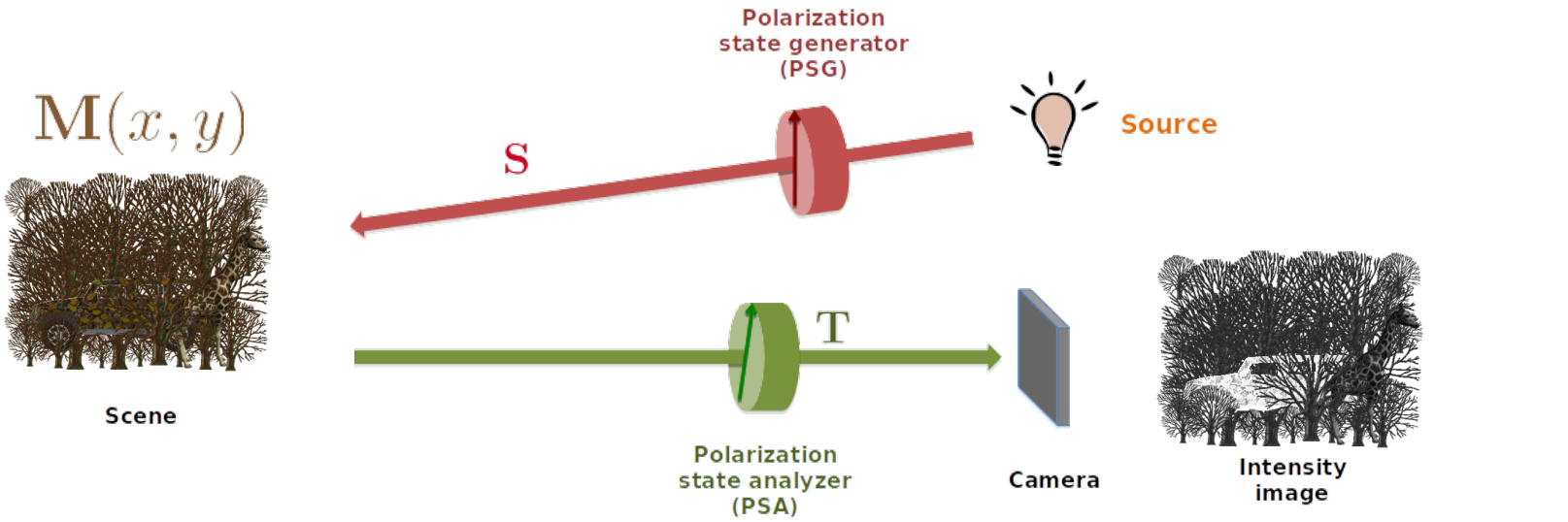
Example 3 : Interferometry

Microscope holographique
(c) LynceeTech



Optical setup
(c) wikipedia

Example 4 : Active polarization imaging

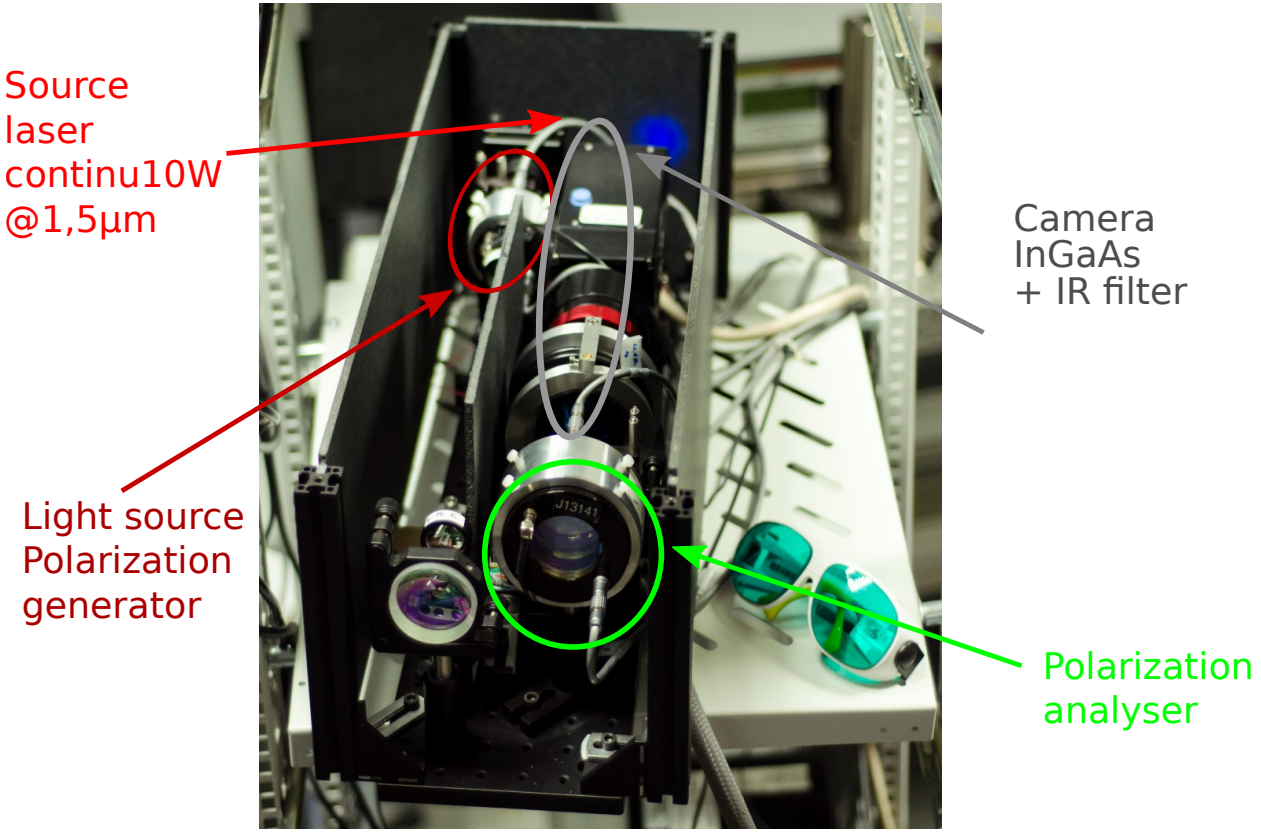


$$i(x,y) \propto \mathbf{T}^t \mathbf{M}(x,y) \mathbf{S}$$

(c) Labo Charles Fabry / IOGS / Thales Research & Technology

* Christophe STOLZ, Vincent DEVLAMINCK, "Imagerie polarimÃ©trique : principes et applications", Techniques de l'ingÃ©nieur, R6722V1.

Example 4 : Active polarization imaging



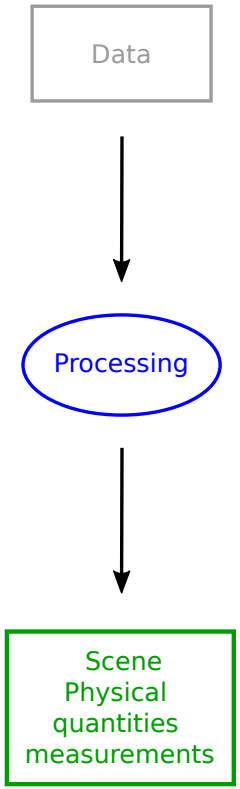
(c) Labo Charles Fabry / IOGS / Thales Research & Technology

* F. Goudail, M. Boffety, L. Leviandier, N. Vannier, "Imagerie polarimetrique active : des applications militaires et duales", Photoniques, 2017.

Data processing

How are the signals/images processed to reconstruct the scene ?

Classical processing



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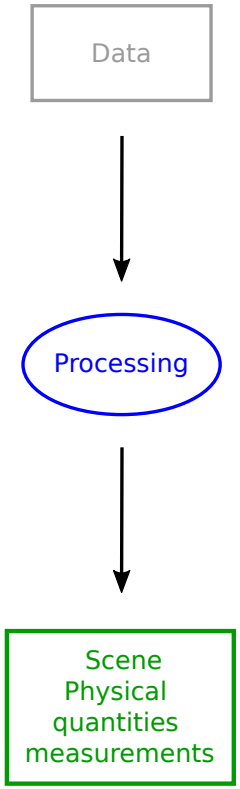
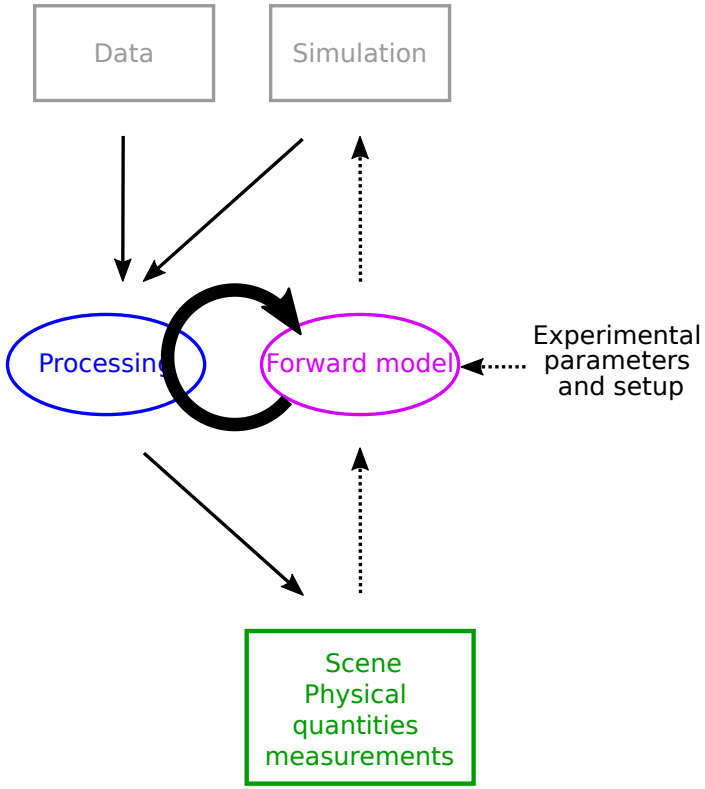


Inverse Problems process



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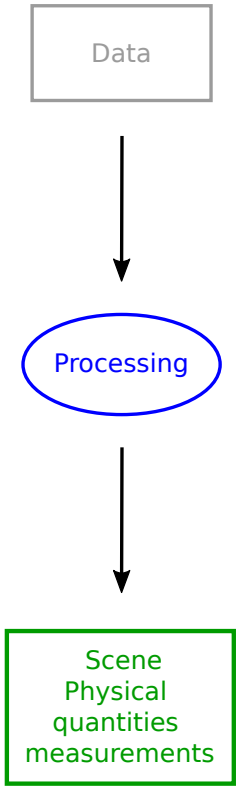

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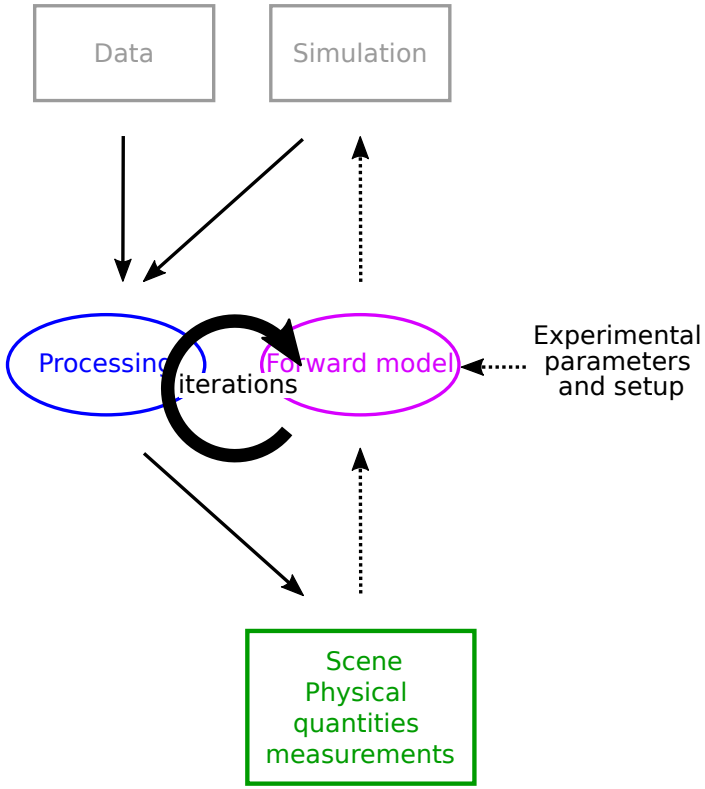
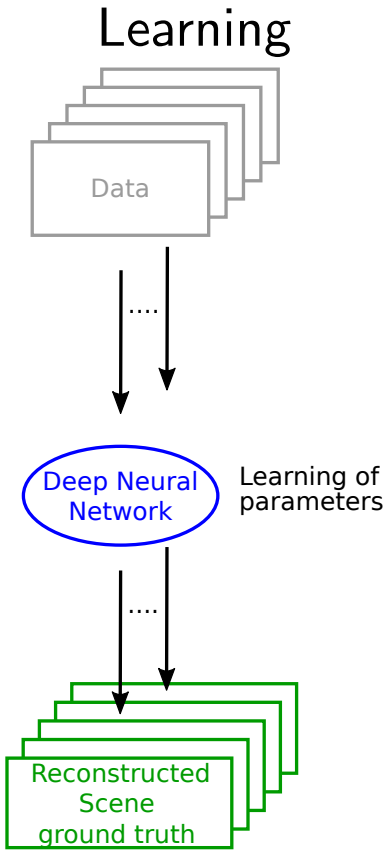


How are the signals/images processed to reconstruct the scene ?

Machine Learning



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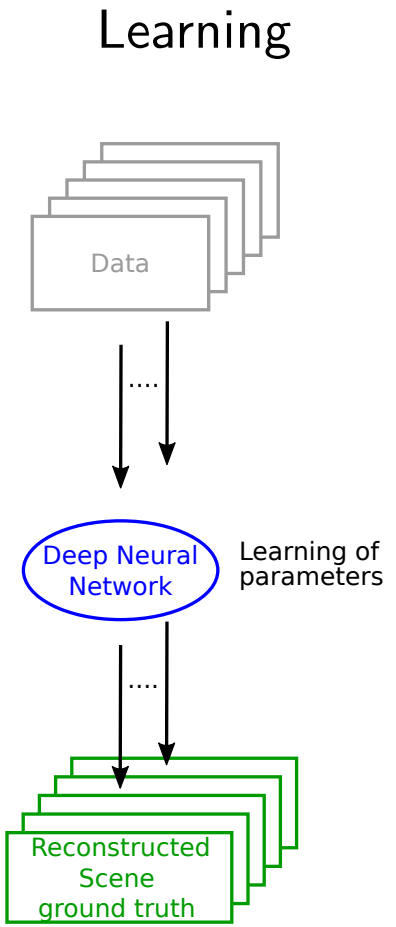

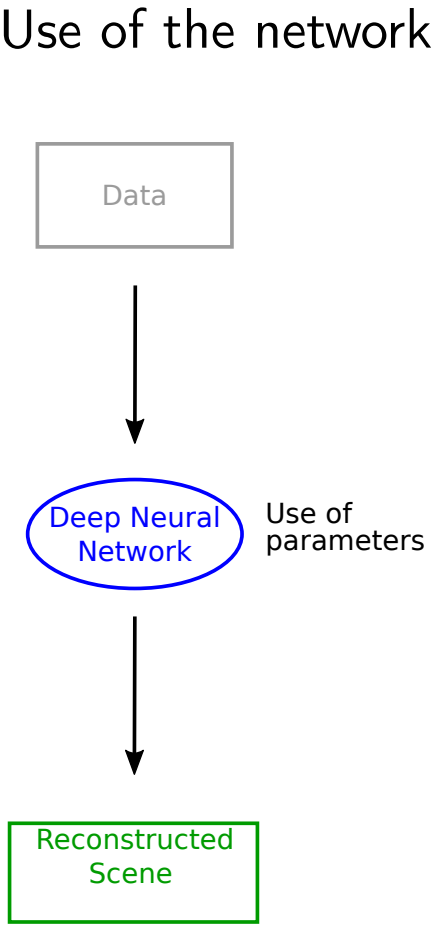

Design of an unconventional imaging system

How to improve the accuracy of the results ?

Accuracy depends on the recording setup and on image processing.
$\Rightarrow$ the design of the setup and the digital processing should be made jointly.

CO-DESIGN

To this aim various skills are required :

- Optics, more generally physics
- Computer science
- Signal processing
- Specific expertise for applications

Co-design

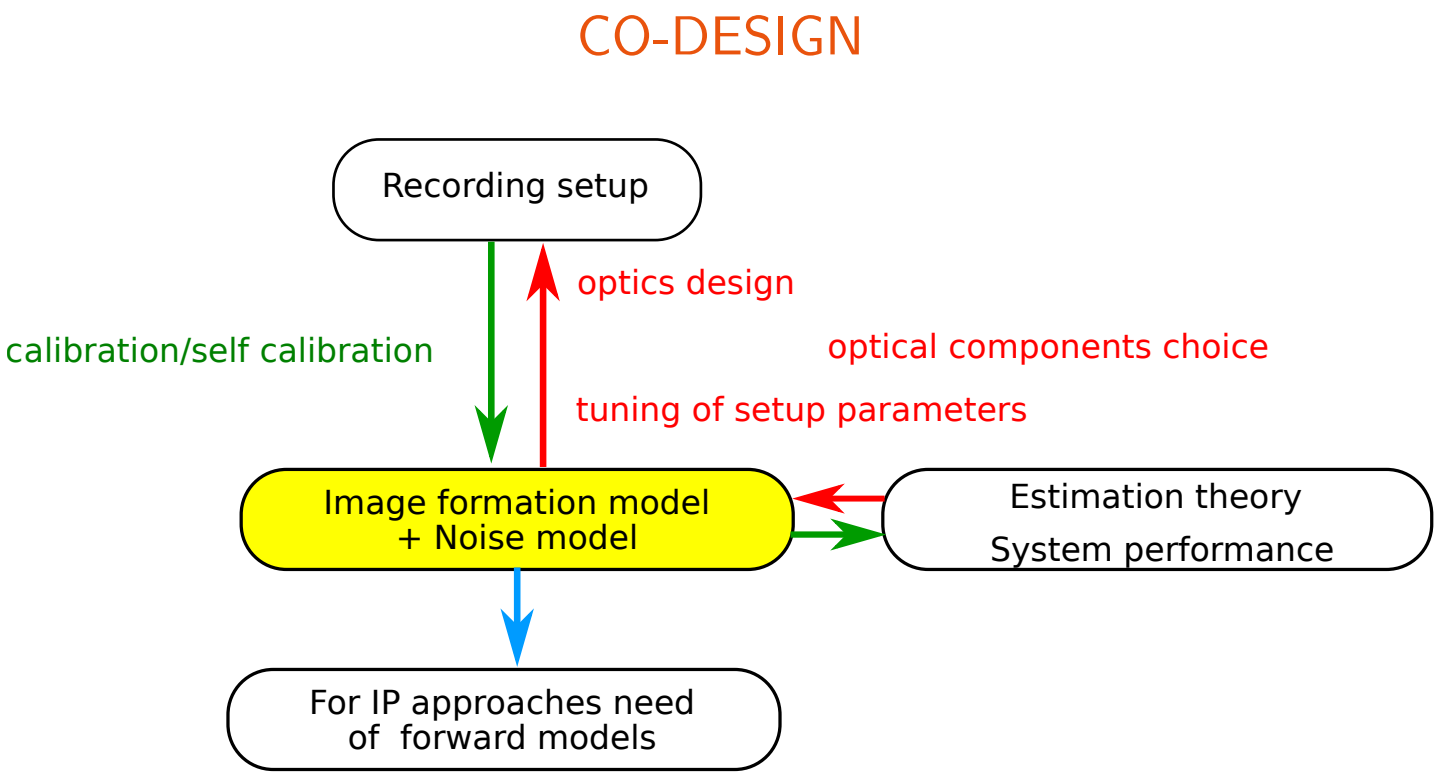
CO-DESIGN
Recording setup
optics design
calibration/self calibration
optical components choice
tuning of setup parameters
Image formation model
+ Noise model
Estimation theory
System performance
For IP approaches need
of forward models

Image formation model knowledge

A good knowledge of the image formation model is mandatory

We need :

- An accurate physical forward model
- An accurate calibration (intrinsic and extrinsic parameters)
  - specific calibration step
  - self-calibration
- Reproductive data (stable setup, ...)

Note : In Machine Learning framework, the NN parameters depend on the physical model, a special care must be paid to the reproducibility of the measurements.