Applications of Deep Learning to Different Optical Systems

Optical Information System Laboratory

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Introduction to Optical Information System Laboratory

Advisor

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Research Interests

- Optical system
- Digital image processing
- Computational imaging
- Machine vision
- Machine learning

Current Projects

Most of our research projects are dependent to the companies in Hsinchu Science Park.

Today

- Introduction to Optical Information System Laboratory
- Deep Learning for Different Optical Systems
  - Optical Coherence Tomography System
  - Phase Retrieval System
  - Instance Segmentation
  - Image Pre-correction System
- Summary

The world around you

- As a human, we are able to transform perceptions (vision, olfaction, hearing, …) into information (words, images, concepts, …).

Cat

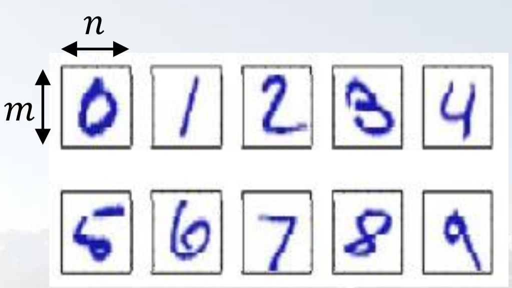
發大財

- **How does your brain translate this information?**
- **How does we introduce this world to our baby?**

The world inside the machine

- To a machine, they are just data with different combinations of "0101…"

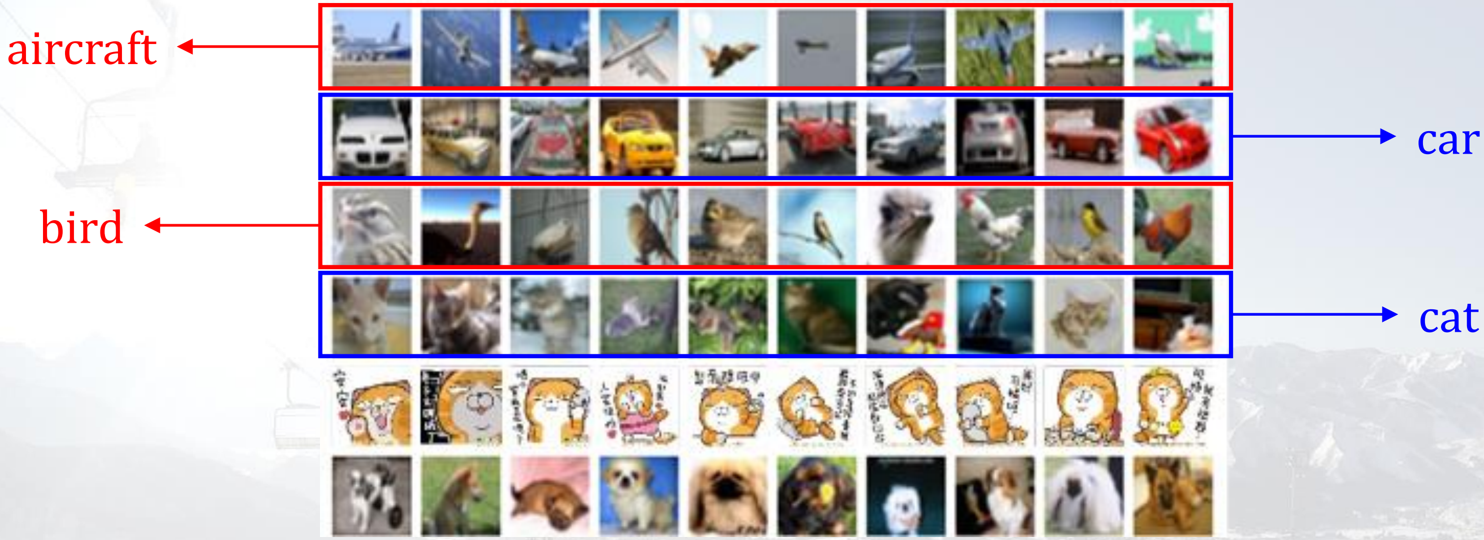
Handwritten digits

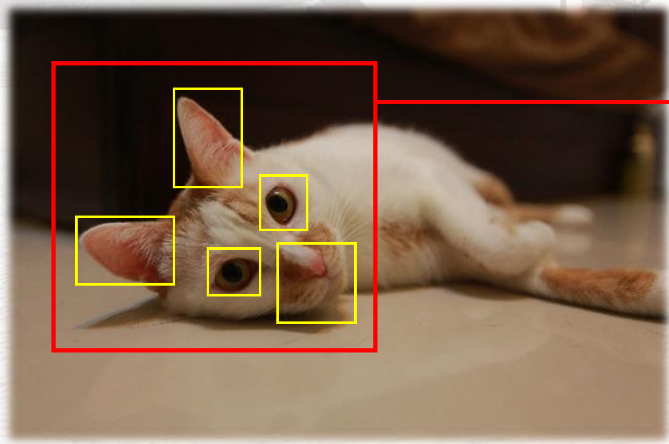


Each image has $m \times n$ pixels.

Machines do not have the ability to tell you what it means.

Vision is the key for human accessing the world





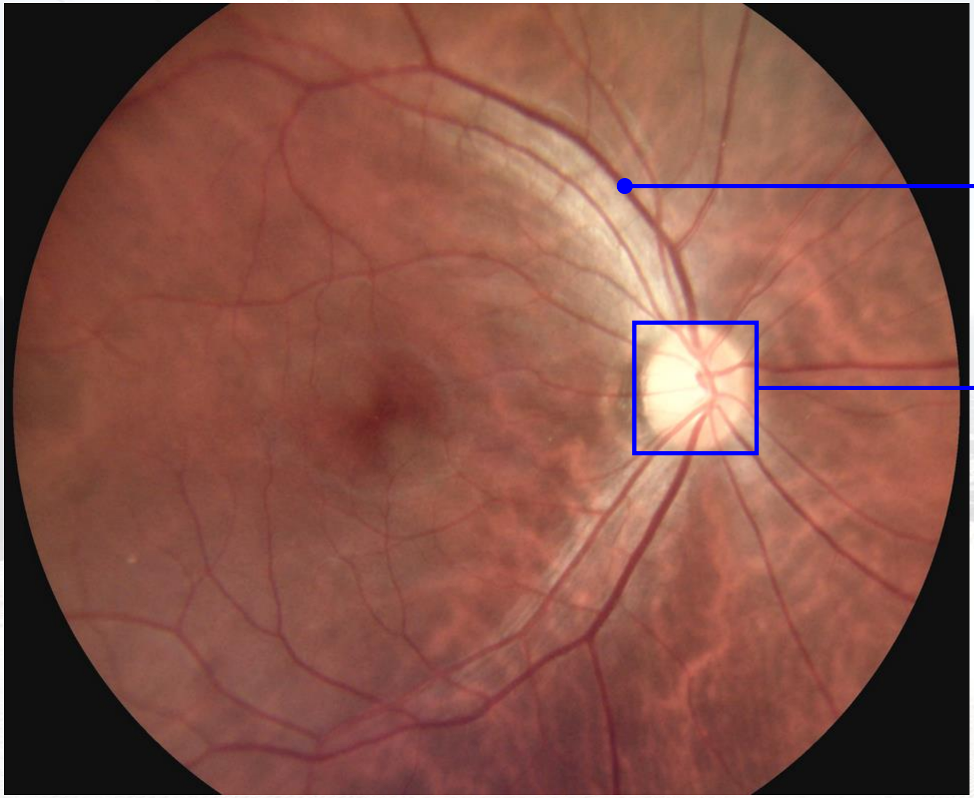
There is a face which consists of

- ✓ 2 cat-like ears
- ✓ 2 cat-like eyes
- ✓ 1 cat-like mouth

➡ This is a cat's face.

Can we expect machine to do this?

Convolution makes it possible



A line-shape filter can receive a peak response

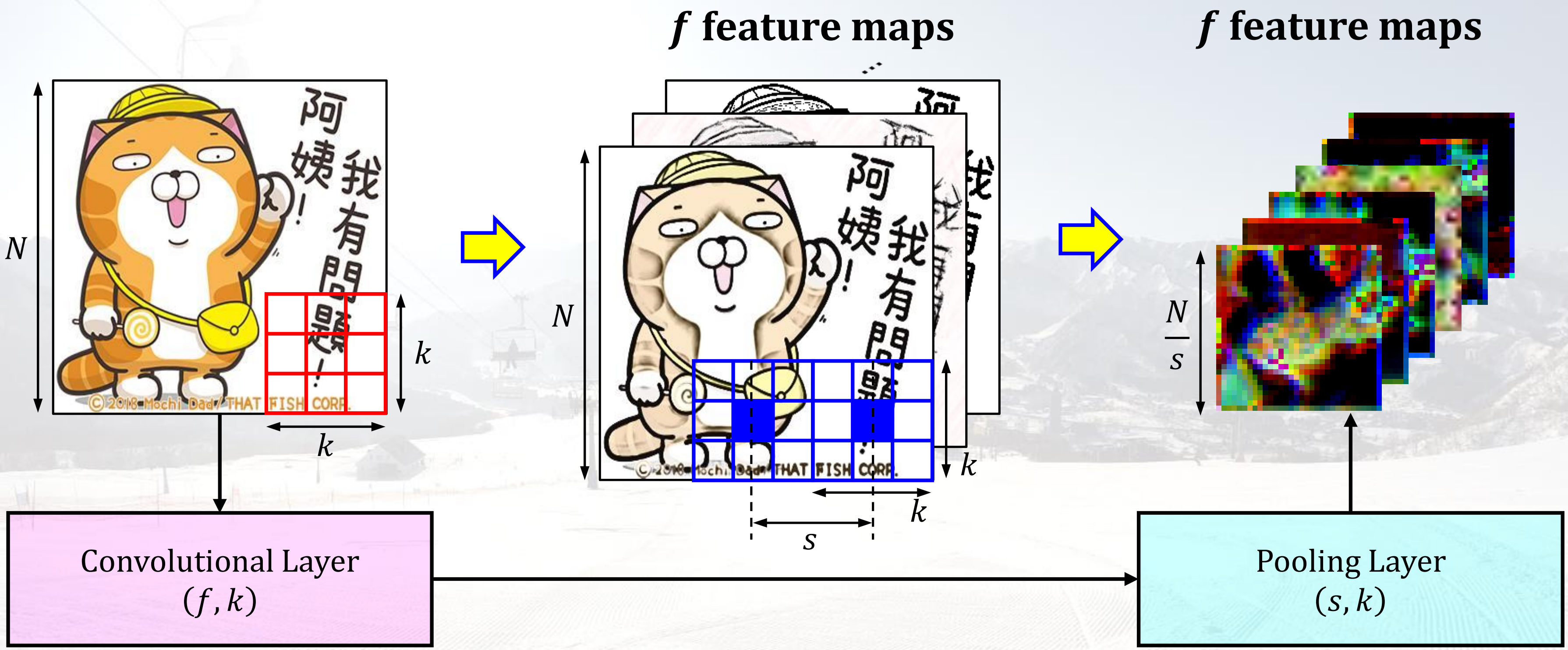
A circle-shape filter can receive a peak response

These are human-defined filter!

This time, we don't tell machines what kind of filters they should use. We don't even tell machines what they should learn.

Fundamentals: convolution and pooling

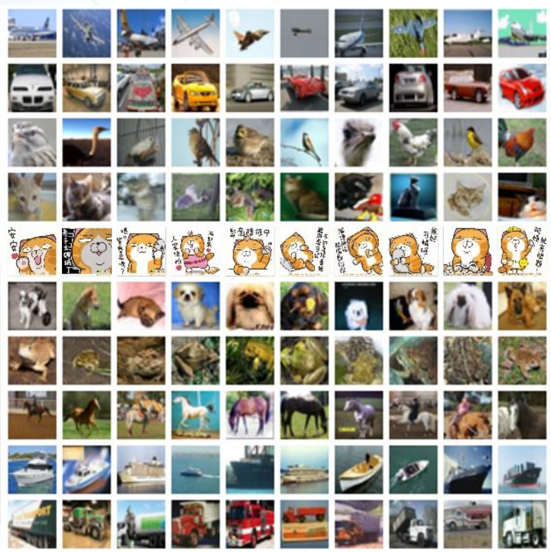
- Illustration of each blocks

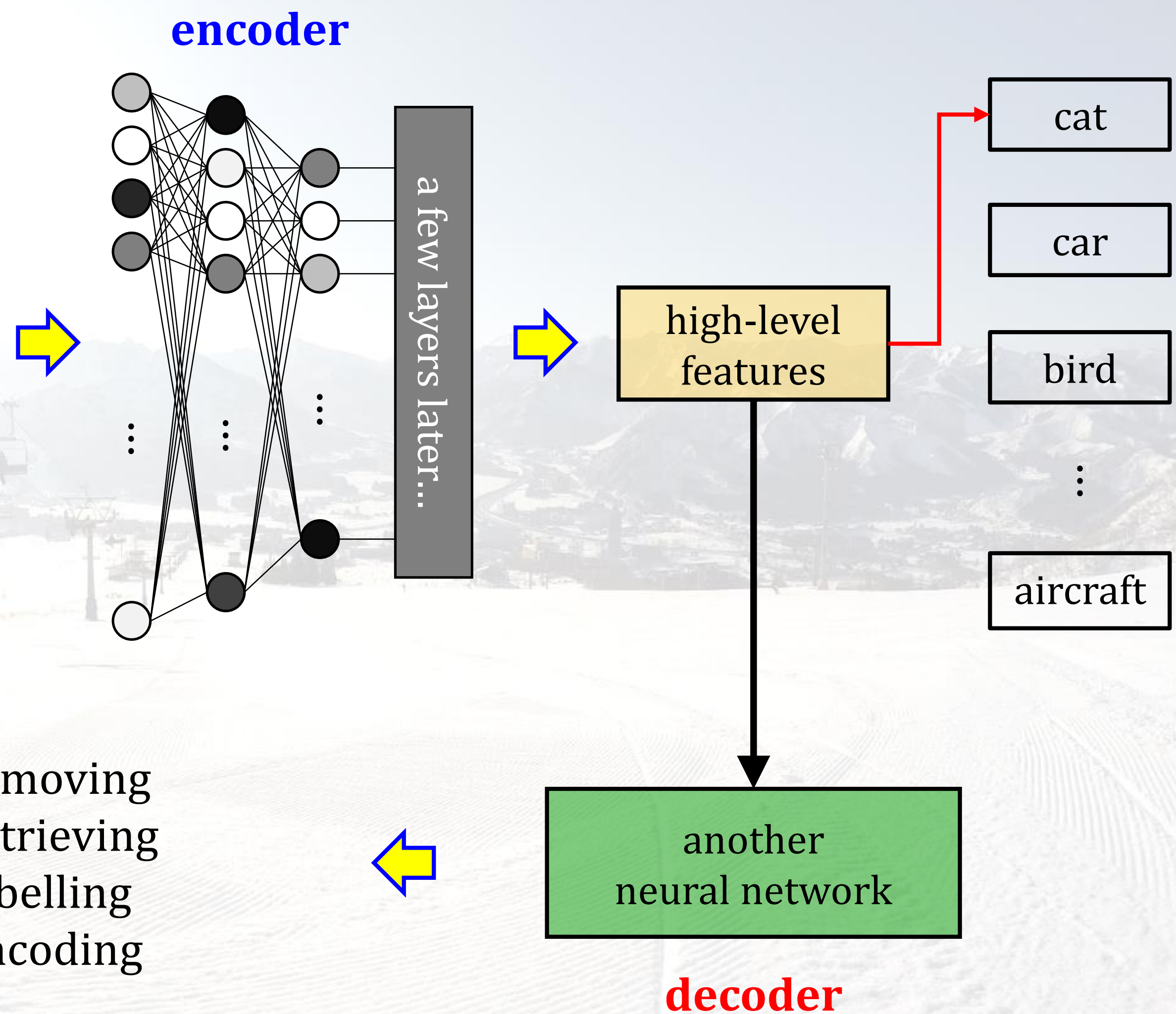


f: number of filters
k: kernel size

s: stride
k: kernel size

An encoding/decoding process



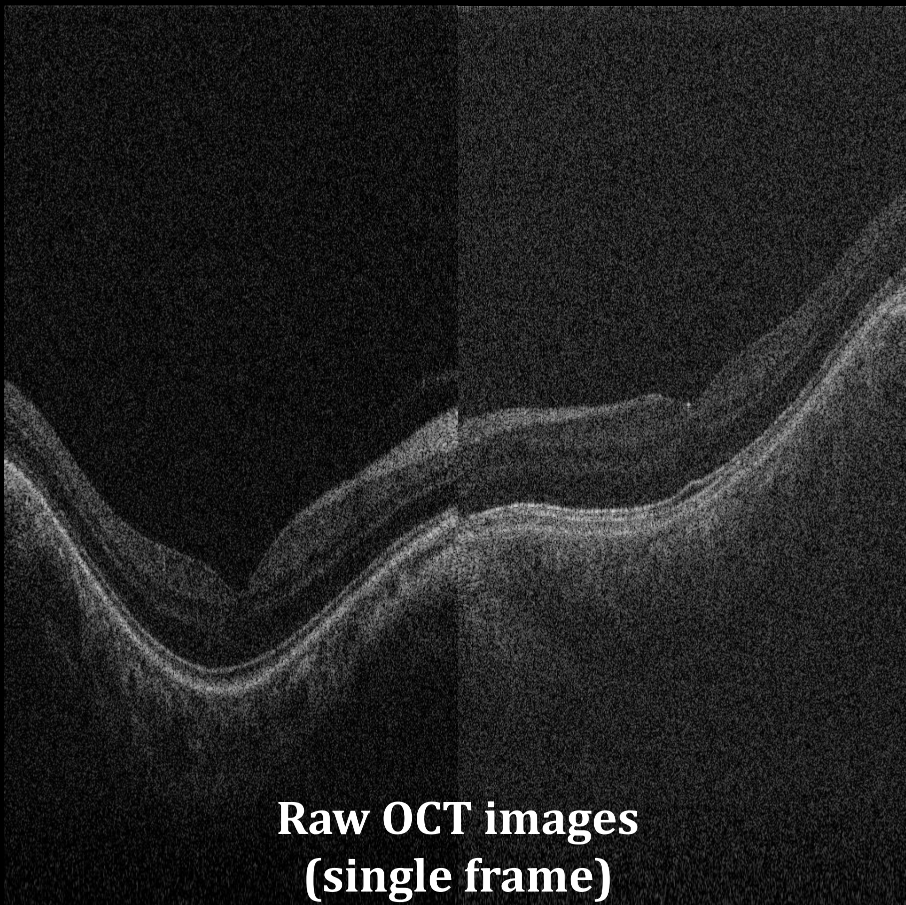


- ✓ Information removing
- ✓ Information retrieving
- ✓ Information labelling
- ✓ Information encoding

Application I

Deep Learning for
Optical Coherence Tomography System

Noise suppression for OCT images



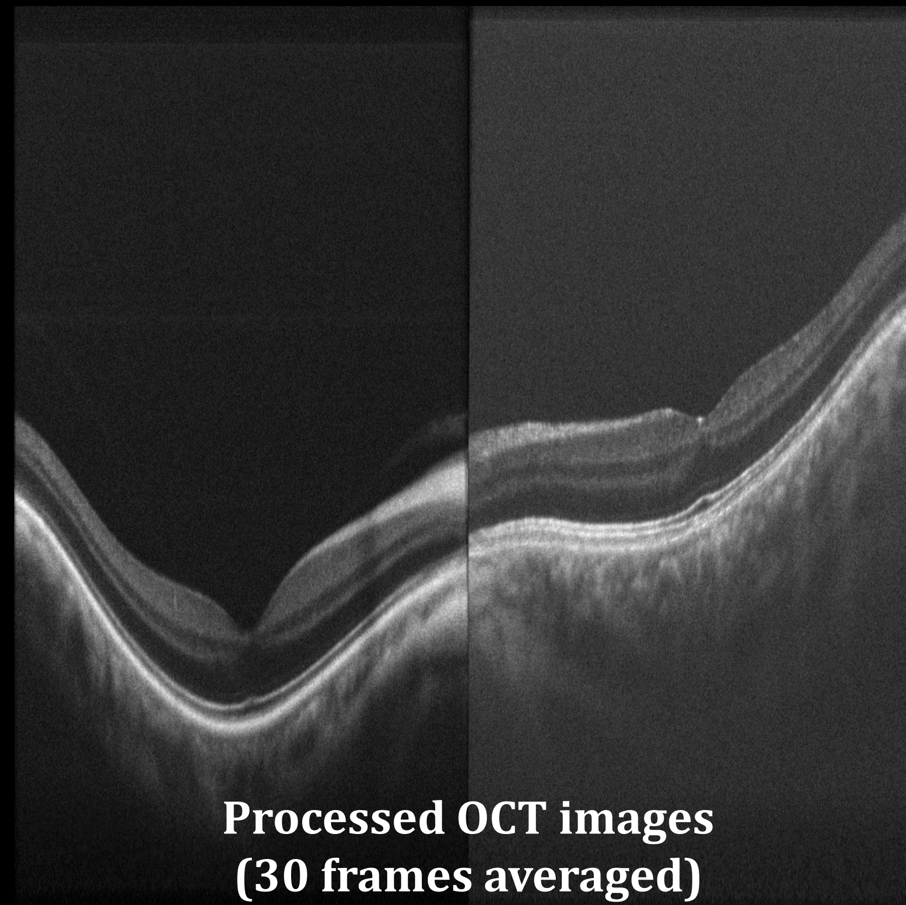
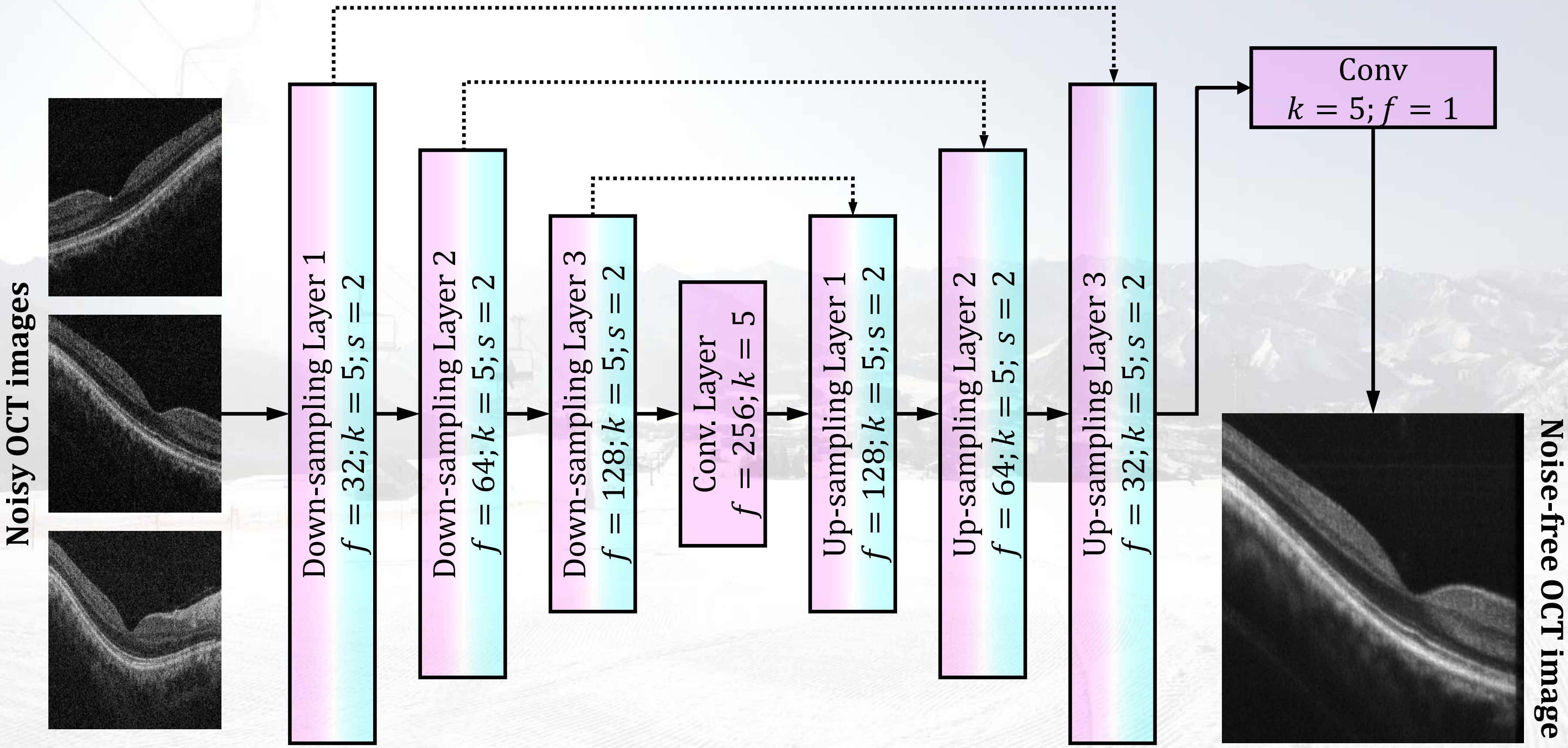


image registration and averaging
(30 frames or more)

execution time: $\sim 10^1$ s

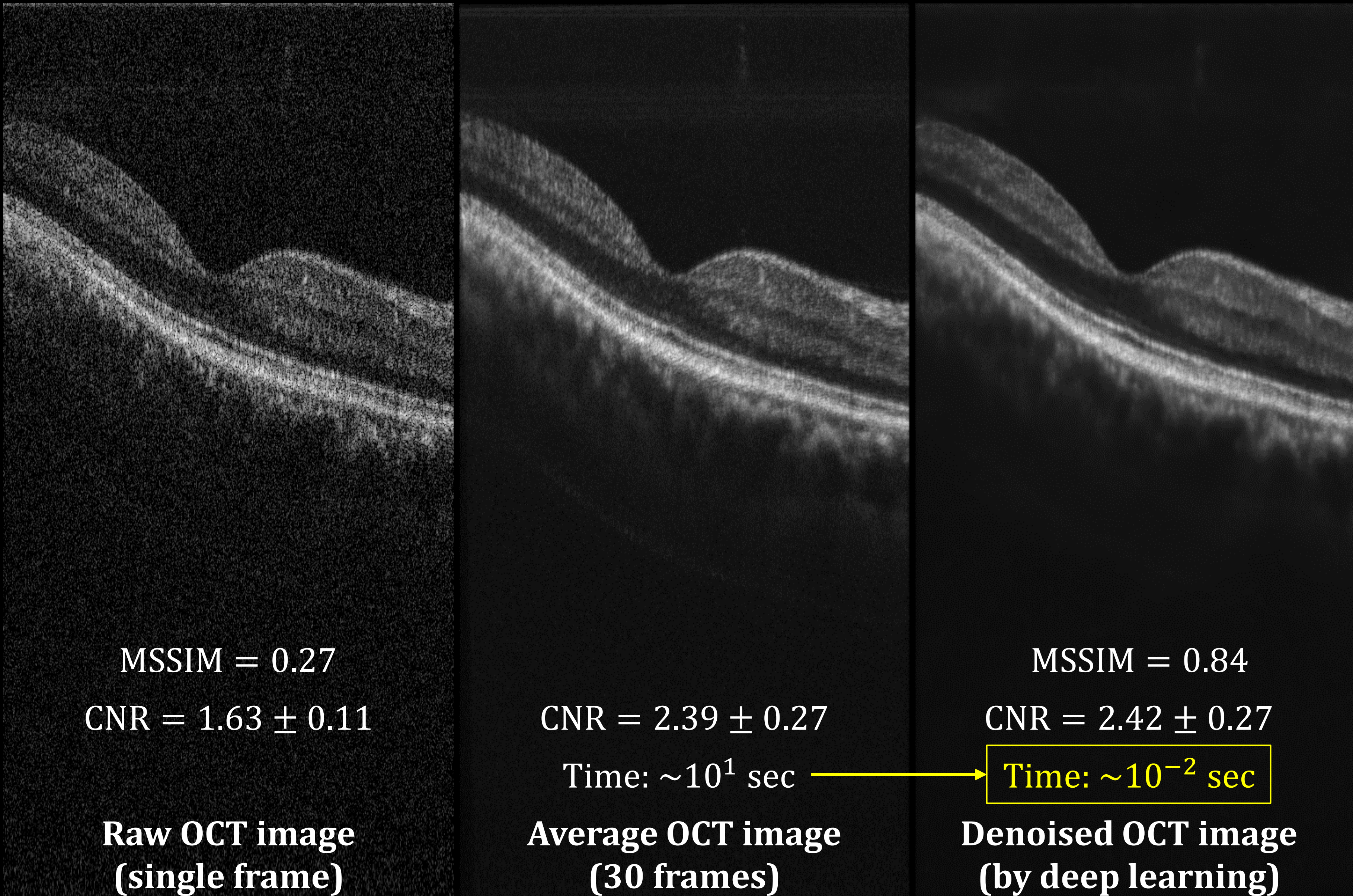
Deep learning for the noise suppression of OCT images



Training GPU: NVIDIA GeForce RTX 2080 Ti

Memory requirement: less than 1 GB for executing the trained model

Results


MSSIM = 0.27
CNR = 1.63 ± 0.11
Raw OCT image
(single frame)
CNR = 2.39 ± 0.27
Time: ~10^1 sec
Average OCT image
(30 frames)
MSSIM = 0.84
CNR = 2.42 ± 0.27
Time: ~10^−2 sec
Denoised OCT image
(by deep learning)

Application II

Deep Learning for Phase Retrieval System

Phase retrieval

- Two kinds of phase information

Fourier phase

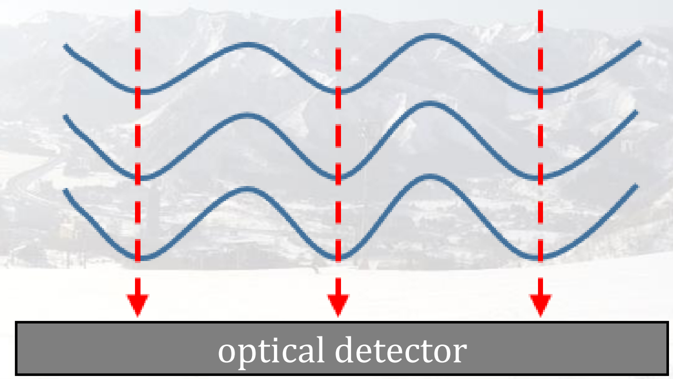
$$|F(\mathbf{k}_r)| \longleftarrow I(\mathbf{r})$$

$$\mathcal{F}\{I(\mathbf{r})\} = F(\mathbf{k}_r)\exp[\boxed{j\phi(\mathbf{k}_r)}]$$

crucial information of image

Local phase (wavefront)

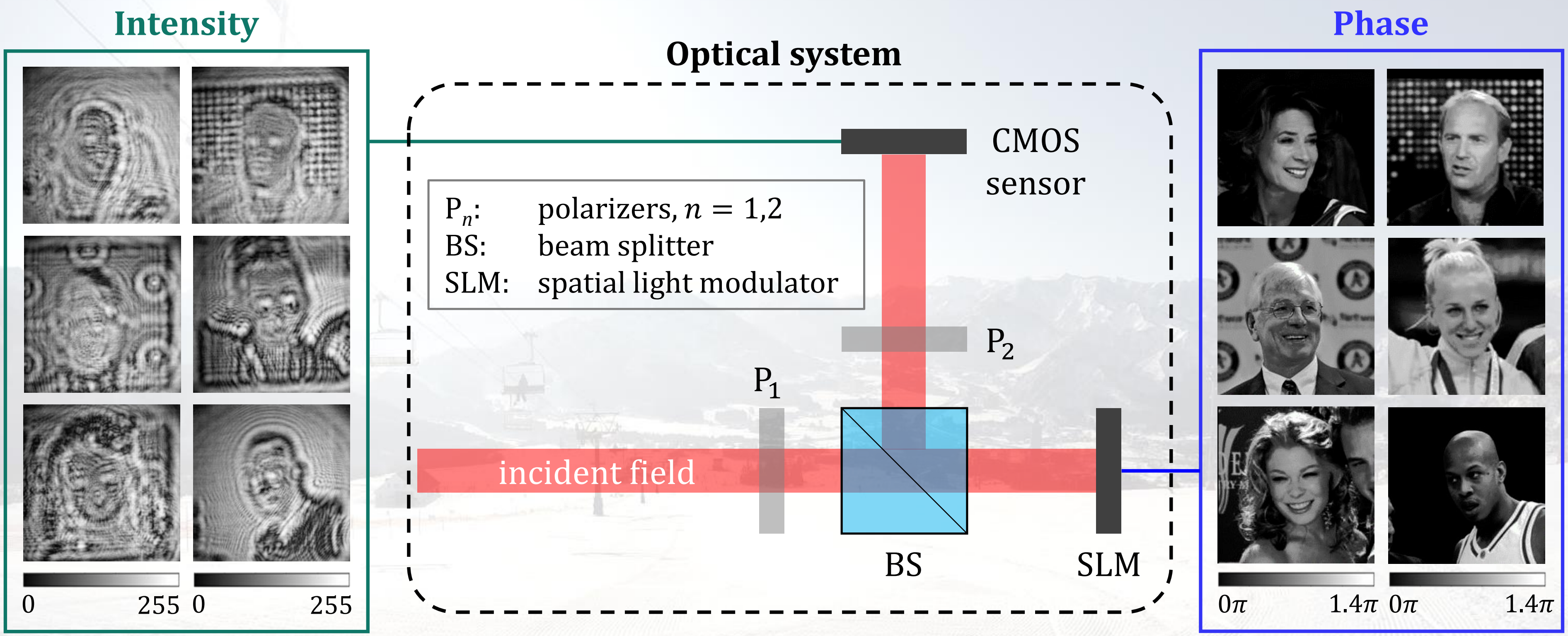
$$E(\mathbf{r}) = A(\mathbf{r})\exp[-j\phi(\mathbf{r})]$$



$$I(\mathbf{r}) = |E(\mathbf{r})|^2 = |A(\mathbf{r})|^2$$

the phase information is lost

Deep learning for phase retrieval



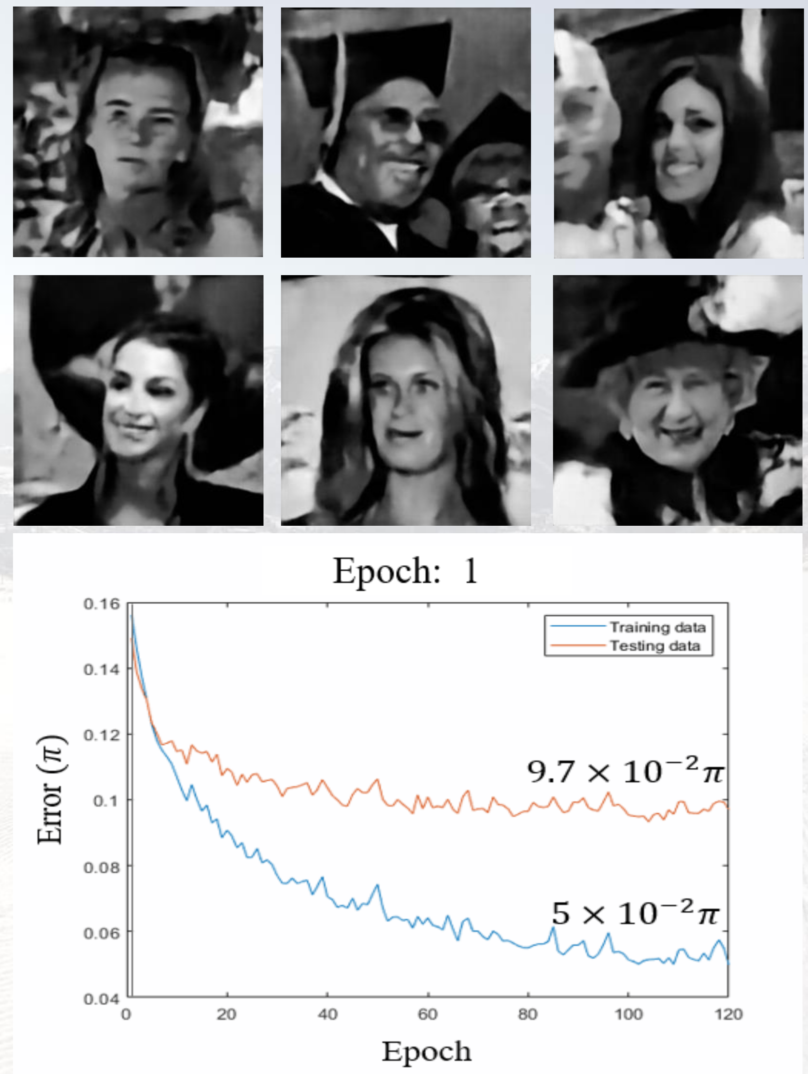
recovery the phase from intensity

$$I(\mathbf{r}) \longrightarrow \phi(\mathbf{r})$$

~~Iterative Fourier transform algorithm~~ → **Deep learning**

Ref: A. Sinha, J. Lee, S. Li, and G. Barbastathis, Optica **4**, 1117-1125 (2017).
G. Barbastathis, A. Ozcan, and G. Situ, Optica **6**, 921-943 (2019).

Results



Ref: Y. Yao, *et al.*, Proc. SPIE **11197**, 111970N (2019).

Summary

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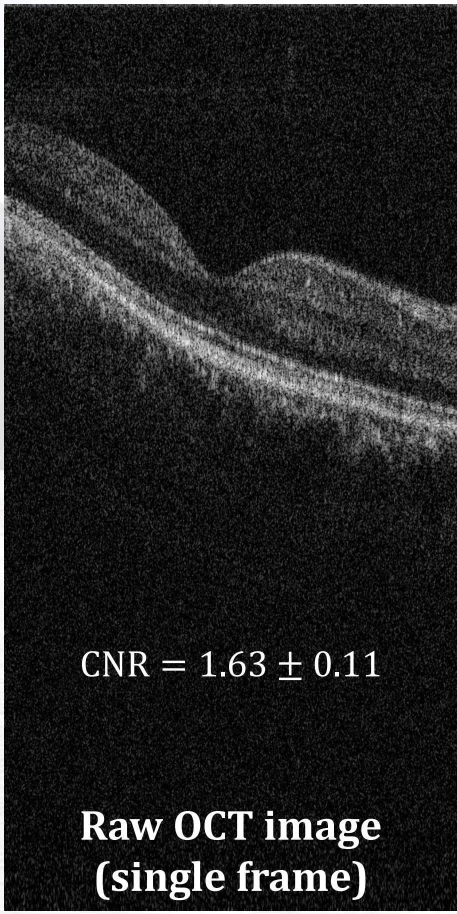
- Perception is an encoding & decoding process. This time, we just let machine learn how to do it by itself, without any designate filter by human.



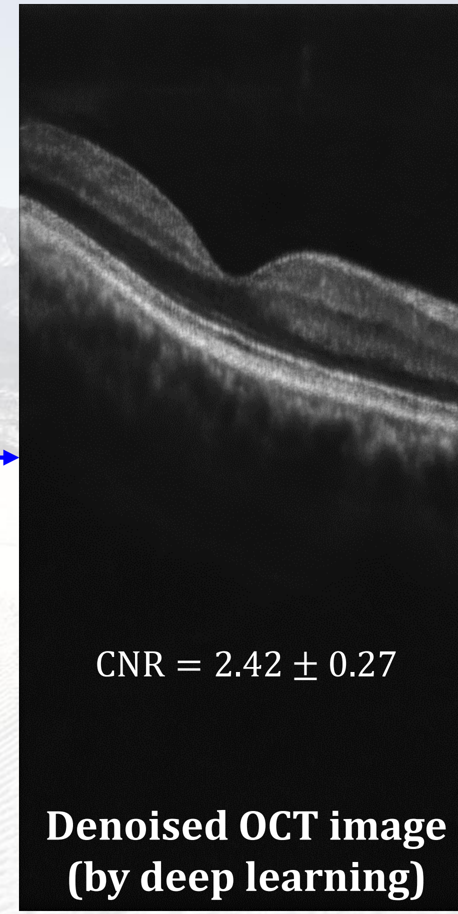
Raw OCT image (single frame)

Once it has been well-trained, we can use it to…

Information removing

encoding → high-level features → decoding

3 orders improvement on execution time ($\sim 10^{1} \rightarrow \sim 10^{-2}$ s)



Denoised OCT image (by deep learning)

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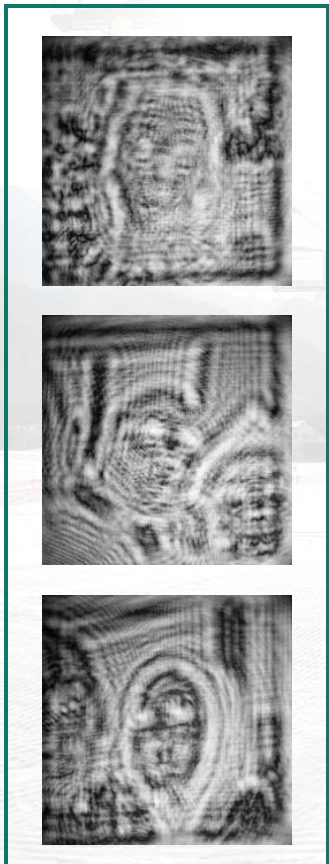

Intensity

Once it has been well-trained, we can use it to…

Information retrieving

encoding → high-level features → decoding

Testing error: $\sim 10^{-1}\pi$

Phase

Thank you!
Please feel free to contact me if you have any question or comment.
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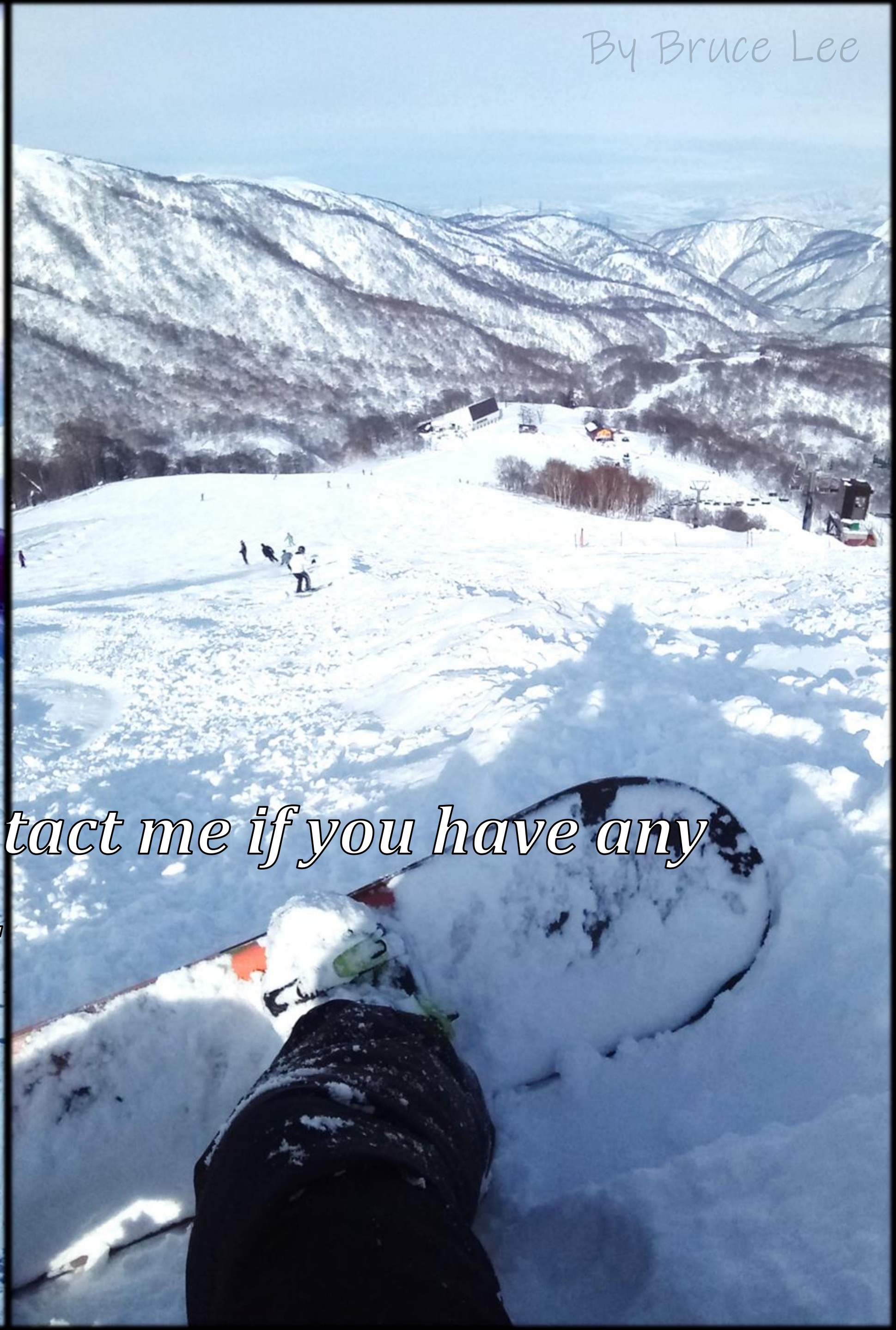

By Bruce Lee