# *Electronic Eyes Using Flexible and Neuromorphic Optoelectronics*

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**March 26th, 2024**

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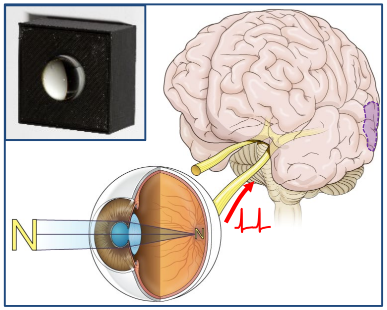
# Introduction

Korea Institute of Science and Technology

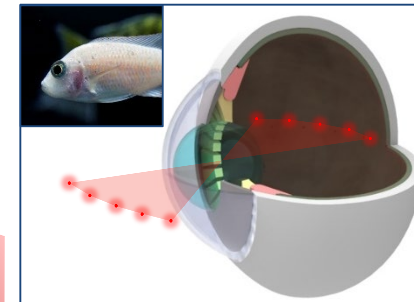
**Bio-inspired Optoelectronics based on flexible/synaptic devices and nanomaterials (2D materials, silicon nanomembrane) will enables Machine Vision Applications.**

***In-sensor processing***



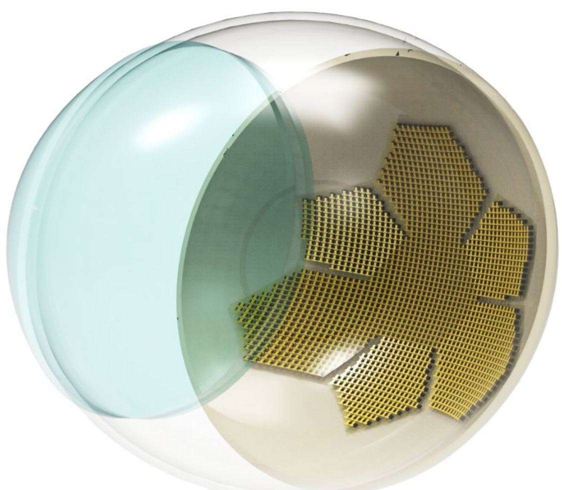
*ACS Nano* **18**, *1241* (2024)
*InfoMat* **6**, *e12479* (2024)
*Adv. Sci.* **10**, *2304039* (2023)
*Sci. Adv.* **8**, *eabq3101* (2022)
*Nature Commun.* **11**, 5934 (2020)

***Bio-inspired camera***



*IEEE JSTQE* **30**, *3800911* (2024)
*IEEE J-FLEX*, **1**, *76* (2022)
*Nature Electron.* **3**, 546 (2020)
*Adv. Funct. Mater.* **28**, 1705202 (2018)
*Nature Commun.* **8**, 1664 (2017)

***Bio-inspired Optoelectronics***



***Flexible/Synaptic device***


*ACS Omega* **8**, 5209 (2023)
*ACS Nano* **17**, 20013 (2023)
*Nano Lett.* **21**, 9153 (2021)
*Nano Lett.* **19**, 2741 (2019)
*Adv. Healthc. Mater.* **5**, 80 (2016)
*ChemNanoMat* **2**, 1006 (2016)
*Adv. Funct. Mater.* **25**, 7109 (2015)
*Nature Commun.* **5**, 5747 (2014)

***Functional Nanomaterials***

*Nano Lett.* **23**, 3344 (2023)
*Adv. Funct. Mater.* **33**, 2210367 (2023)
*Acc. Chem. Res.* **52**, 73 (2019)
*Adv. Mater.* **29**, 1702902 (2017)
*Adv. Mater.* **28**, 9326 (2016)
*Nature Commun.* **6**, 7149 (2015)

**From C. Choi's Publications**
**Blue indicates corresponding-author/first-author papers**

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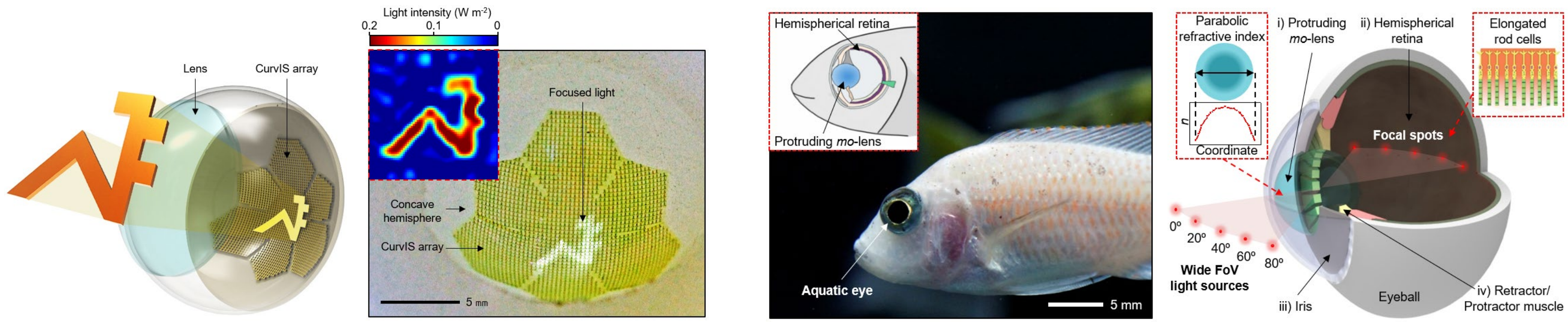
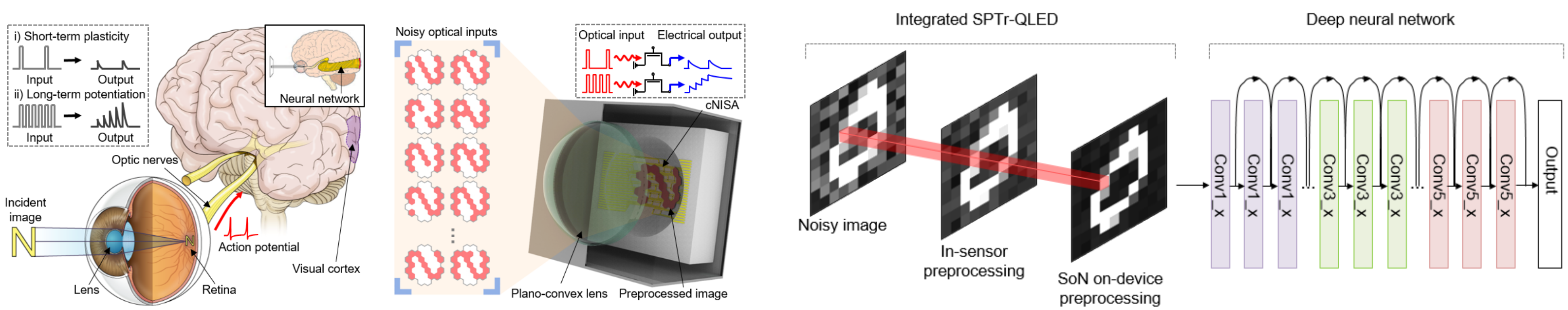



C. Choi *et al.* Nature Commun. **8**, 1664 (2017), C. Choi *et al.* Nature Electron. **3**, 546 (2020)

## Part 2

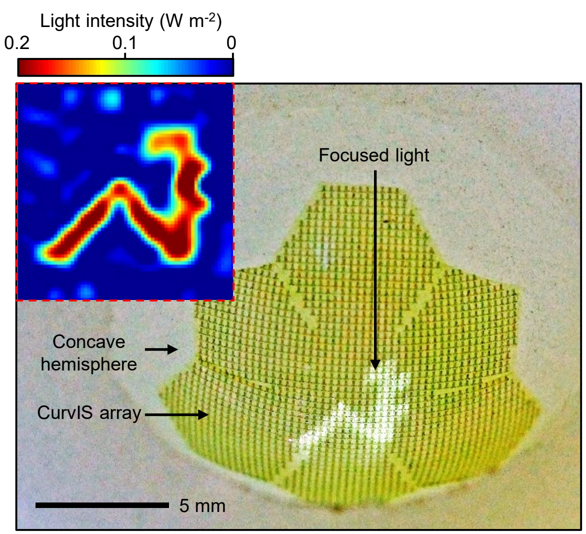
### *Synaptic optoelectronic devices for in-sensor preprocessing*

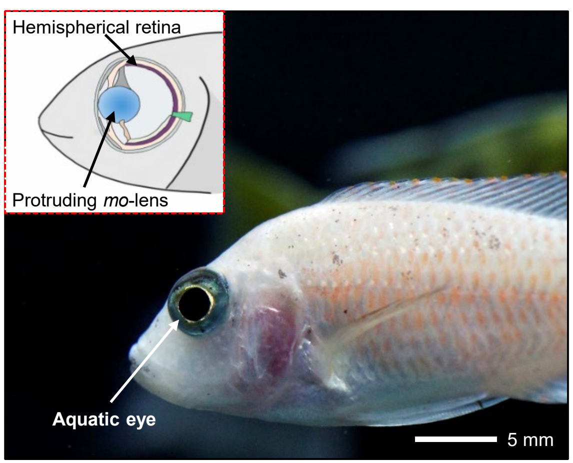



C. Choi *et al.* Nature Commun. **11**, 5734 (2020), C. Choi *et al.* Sci. Adv. **8**, *eabq3101* (2022)
C. Choi *et al.* Adv Sci. 2304039 (2023), C. Choi *et al.* InfoMat. (*early view*)

# Part 1

## Bio-inspired camera based on flexible optoelectronics



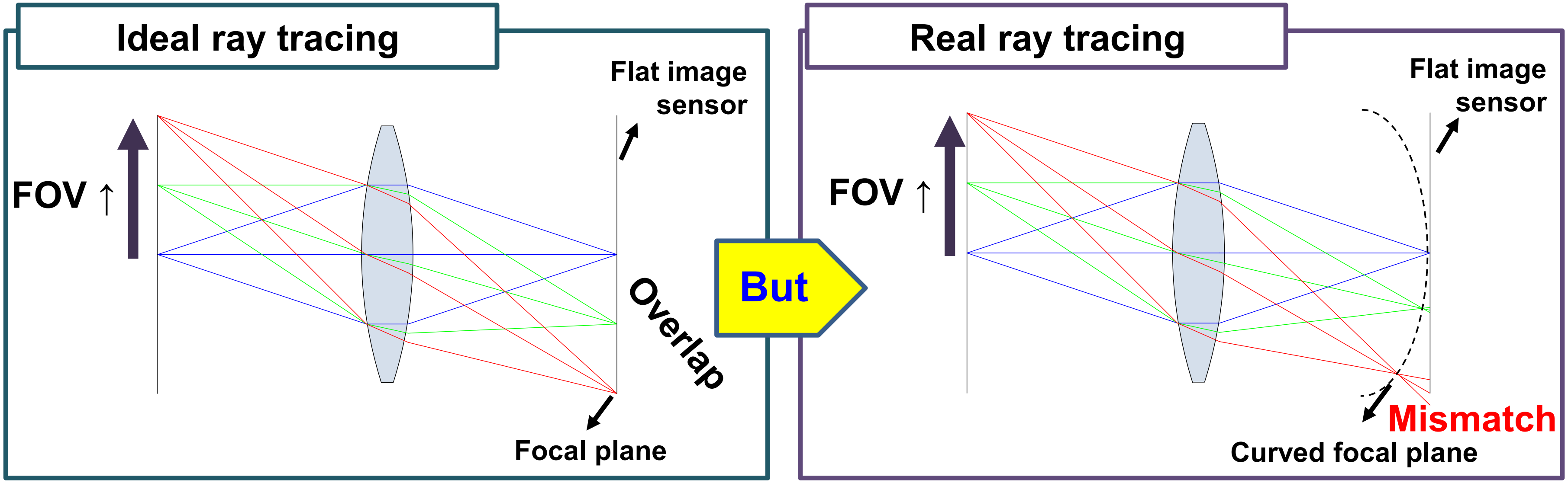




C. Choi *et al.* *Nature Commun.* **8**, 1664 (2017), C. Choi *et al.* *Nature Electron.* **3**, 546 (2020)

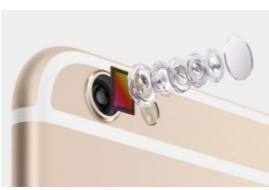
# Issue of conventional Cameras

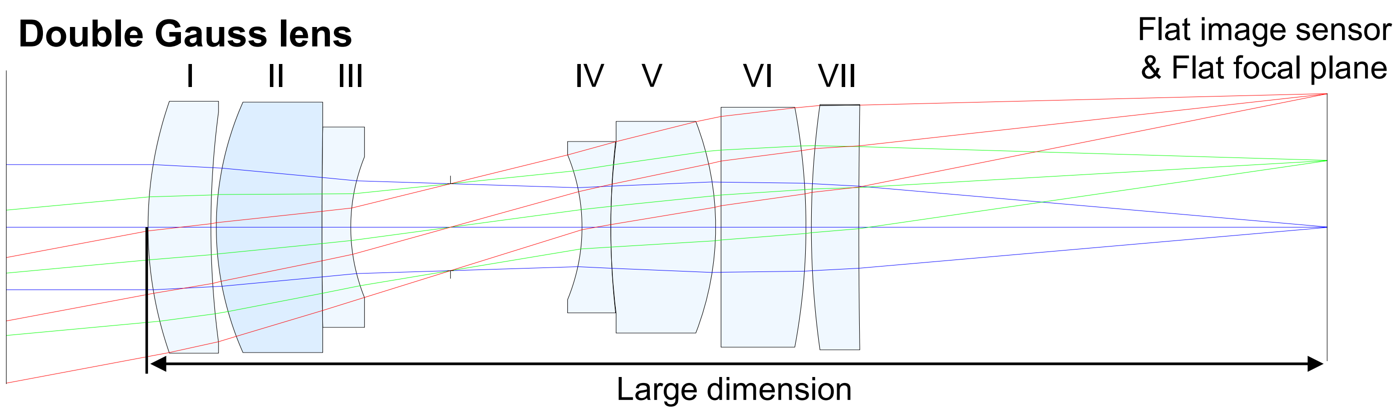


## 1. "Optical aberration" in conventional cameras with single lens optics



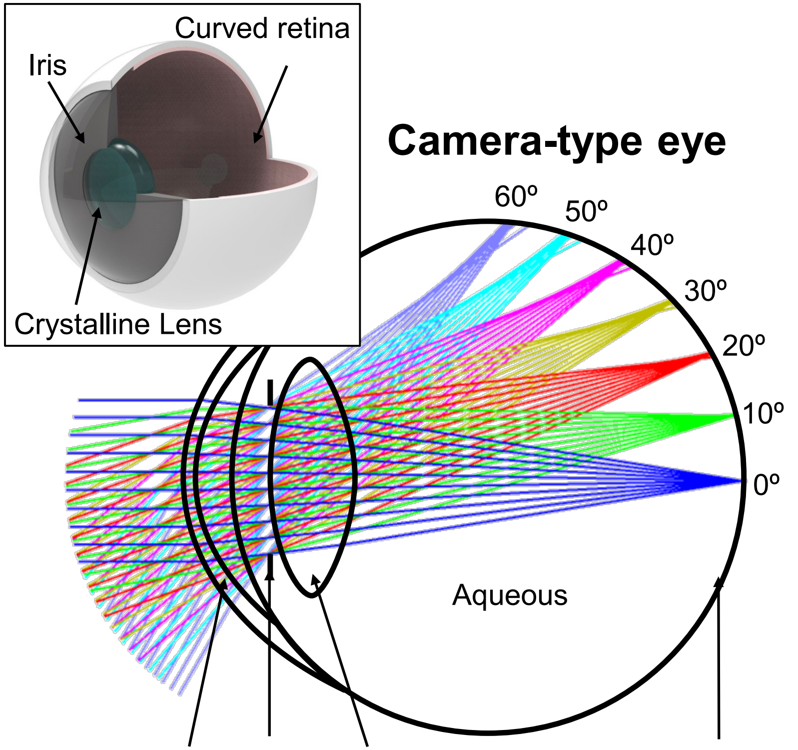

## 2. "Complicated optics" are expensive, heavy, and bulky.

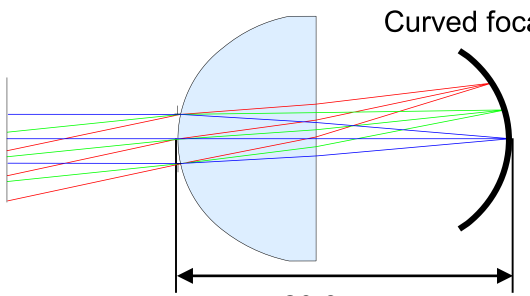


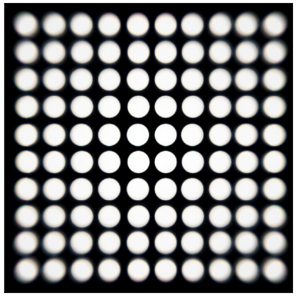



# Inspiration from camera-type eyes

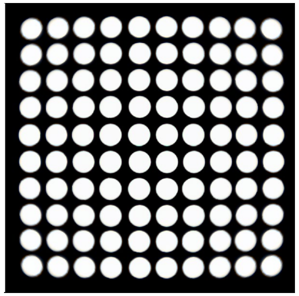
## Optical advantages of camera-type eye



Single lens with flat image sensor

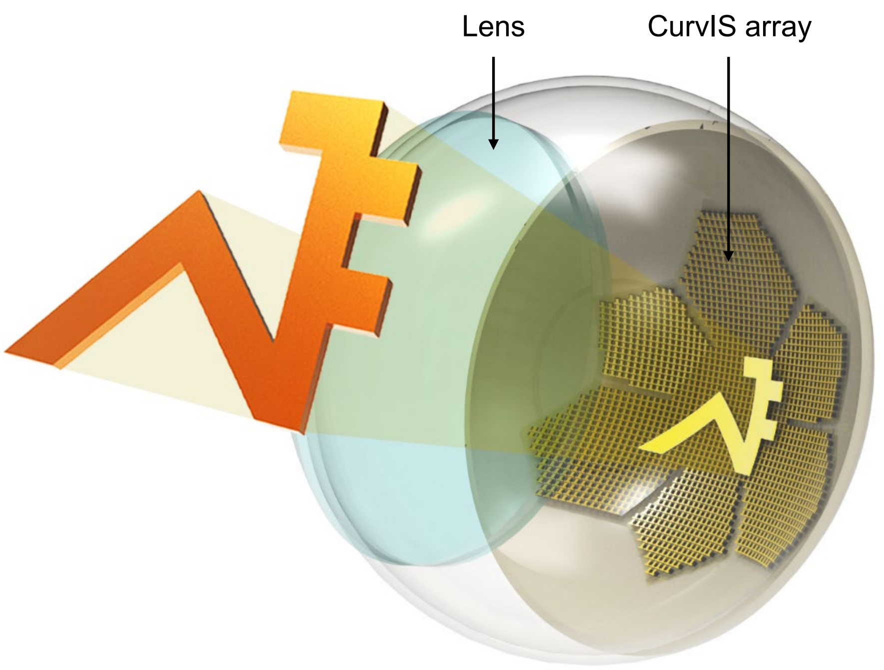


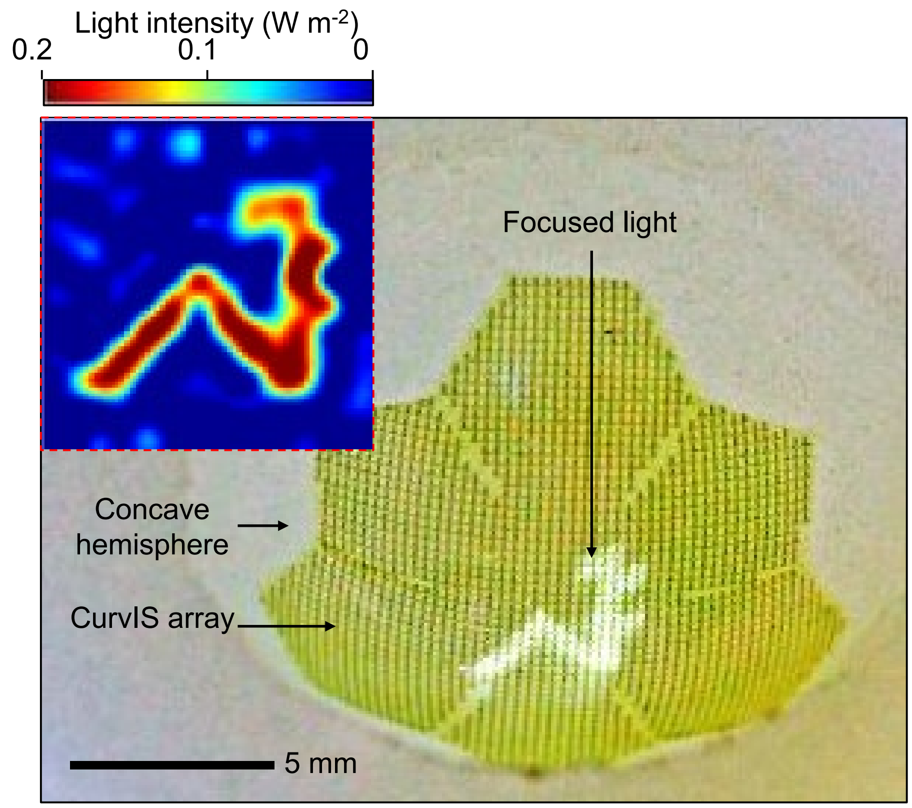
Single lens with CurvIS array

⇒ **Compared to complicated multi-lens configuration in conventional camera, the camera-type eyes in nature enable the aberration-free imaging using single-lens optics by matching the retina with the curved retina.**

# Human eye-inspired camera

## Human eye-inspired high-density curved image sensor array



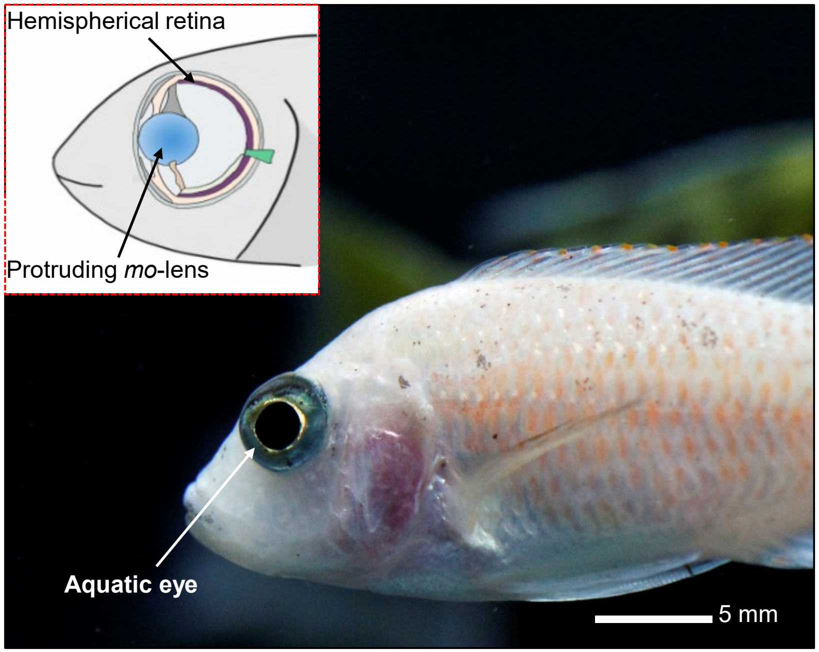

- ⇒ **Ultrathin image sensor array using $MoS_2$/graphene heterostructure.**
- ⇒ **High-density curved image sensor array without mechanical failure.**
- ⇒ **Human-eye-inspired configuration (Curved imager and single lens optics).**
- ⇒ **Various optical advantages (reduced optical aberration, single-lens optics).**

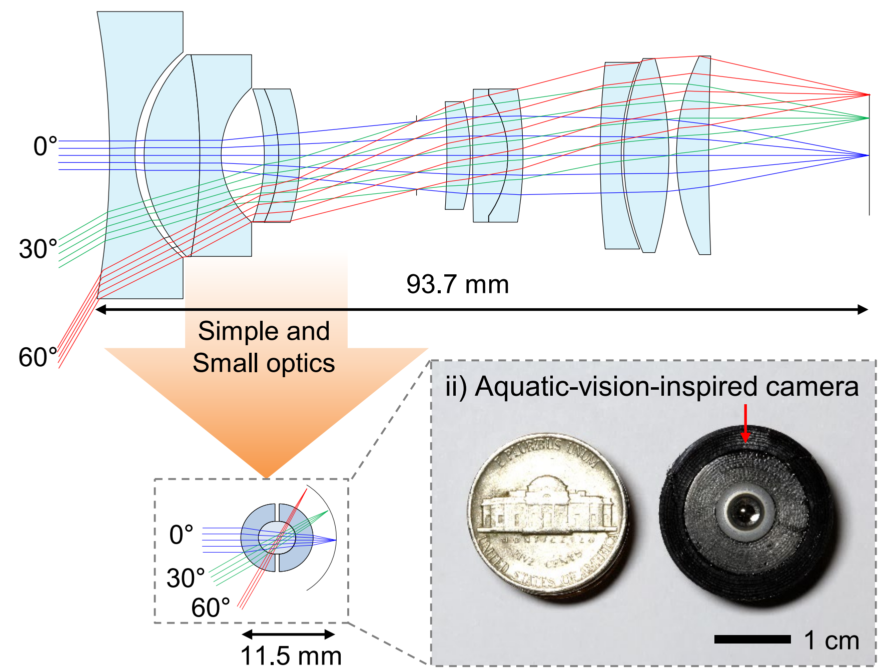


C. Choi *et al.* *Nature Commun.* **8**, 1664 (2017)

# Aquatic vision in nature

## Aquatic vision in nature: Simple optics & Wide FoV




⇒ **Aquatic vision (*e.g.*, fisheye) enables wide field-of-view imaging (>160°) based on a single lens optics, because of their spherical lens and hemispherical retina.**

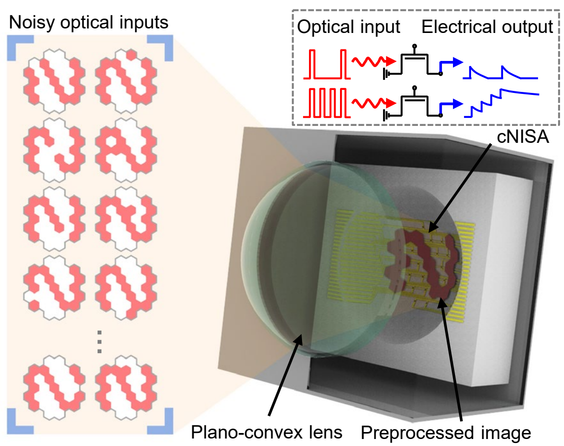
⇒ **Aquatic vision-inspired camera using silicon hemispherical image sensor array for wide field-of-view, deep depth-of-field imaging with a miniaturized form factor.**

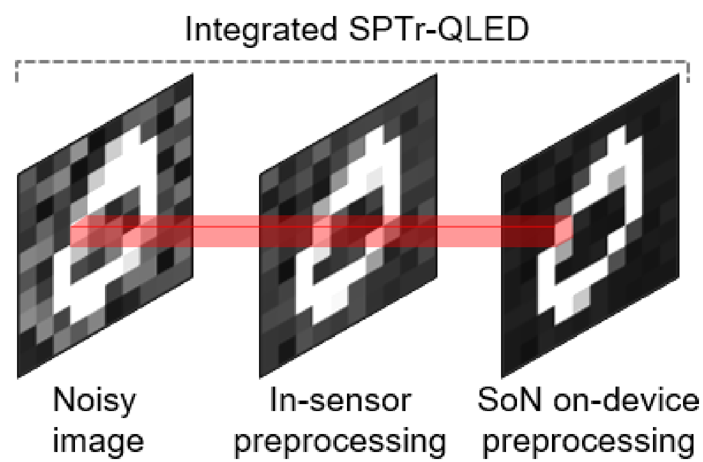


C. Choi *et al.* *Nature Electron.* **3**, 546 (2020)

# Part 2

## *Synaptic optoelectronic devices for in-sensor preprocessing*



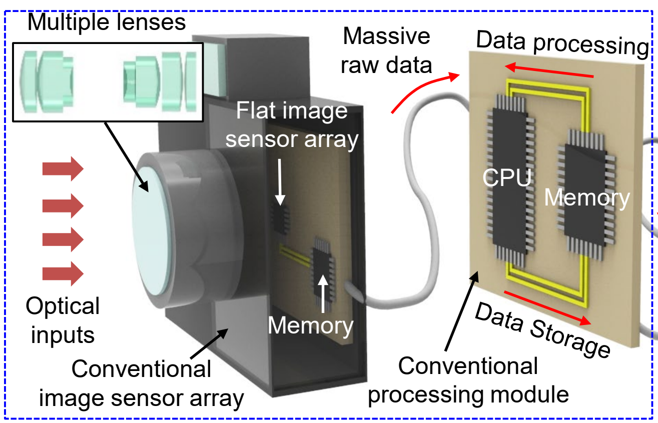




C. Choi *et al.* *Nature Commun.* **11**, 5734 (2020), C. Choi *et al.* *Sci. Adv.* **8**, *eabq3101* (2022)
C. Choi *et al.* *Adv Sci.* 2304039 (2023), C. Choi *et al.* *InfoMat.* (*In press*)

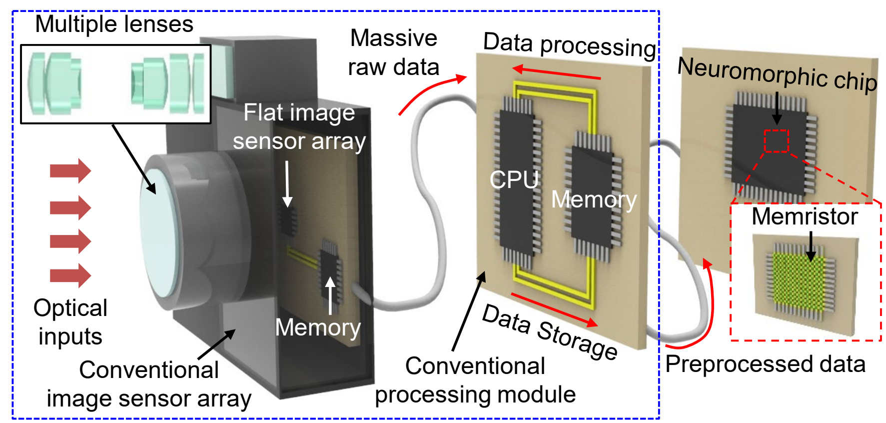
# Conventional image recognition

## Conventional imaging and data processing systems

**Conventional imaging system with conventional processor**

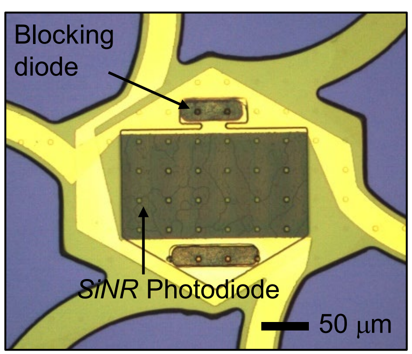


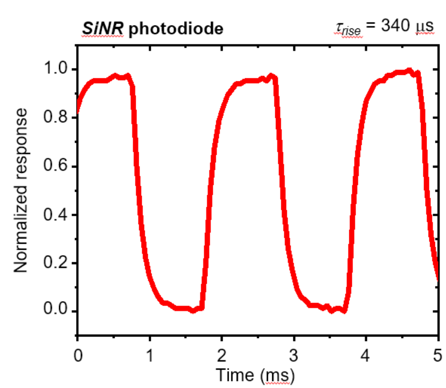

**Conventional imaging system with neuromorphic chips**




C. Choi *et al.* Nature Commun. **11**, 5934 (2020)

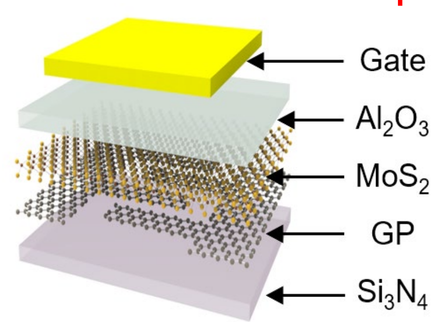
## Conventional Si image sensors – fast photoresponse

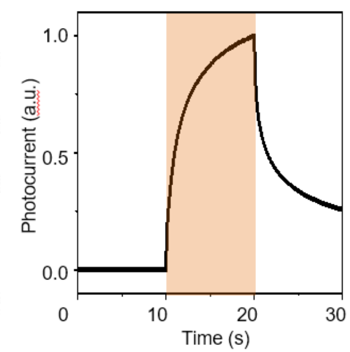



**VS**

**Unconventional photoresponse:**
**slow and persistent**



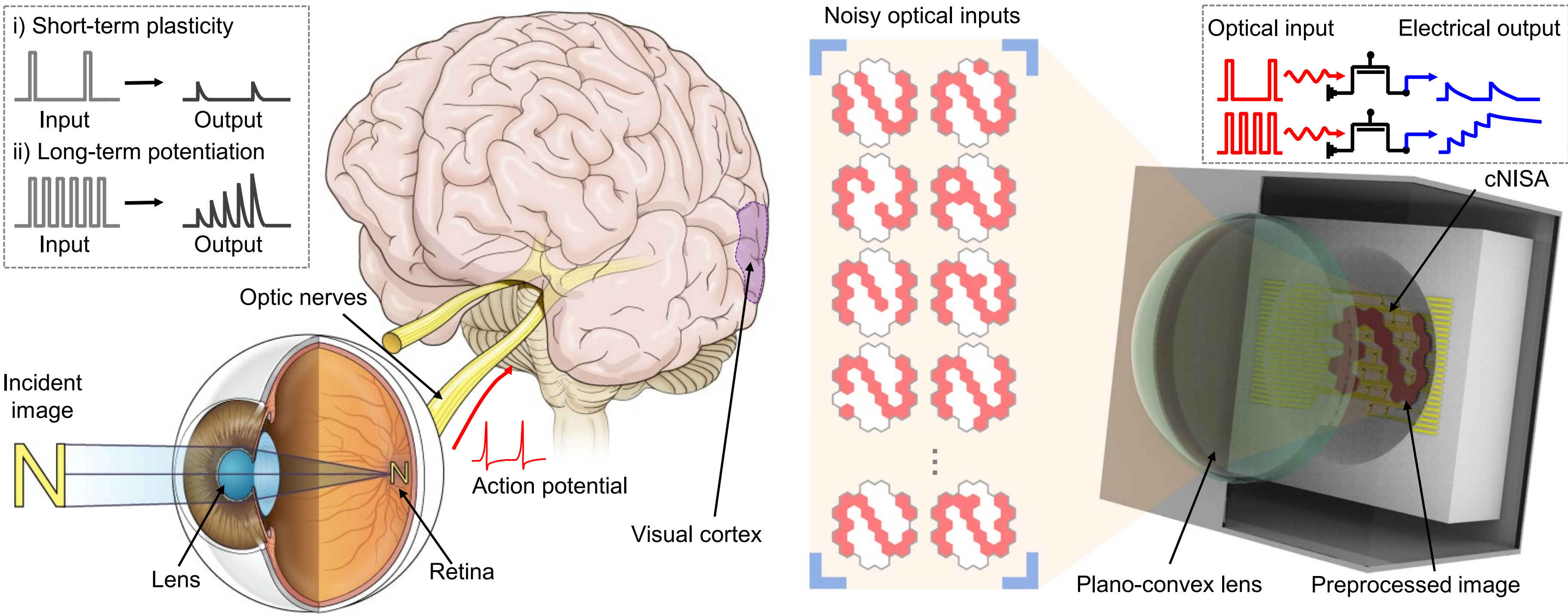




C. Choi *et al.* Nature Electron. **3**, 546 (2020)

C. Choi *et al.* Nature Commun. **8**, 1664 (2017)

# Curved neuromorphic image sensor

## cNISA inspired by human visual recognition system




⇒ **Curved neuromorphic image sensor array for aberration-free imaging with a single lens optics and preprocessing with photon-triggered synaptic plasticity.**

⇒ **The preprocssed image, of which noise is reduced and contrast is enhanced, can be derived from the noisy optical inputs through a single-readout operation.**



C. Choi *et al.* *Nature Commun.* **11**, 5934 (2020)

# Synaptic photodetector for CP light

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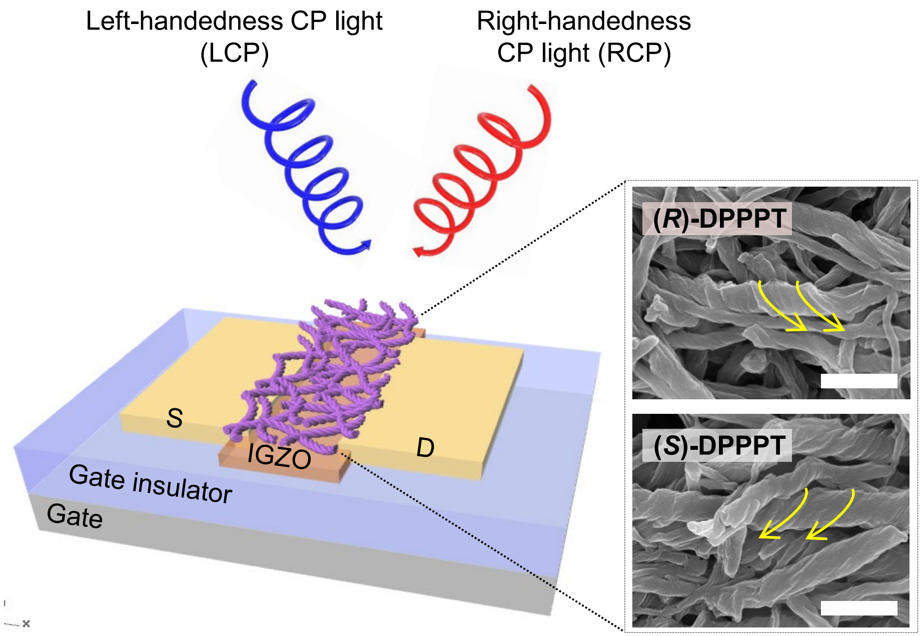
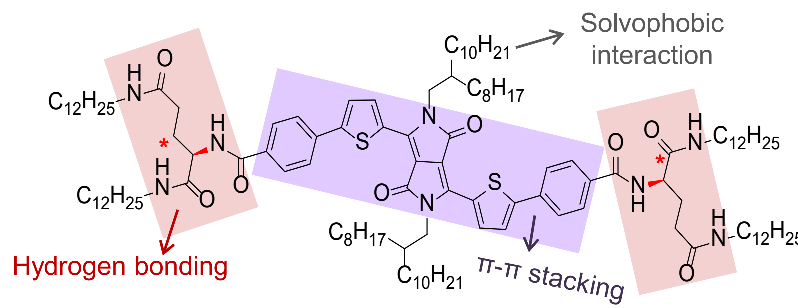
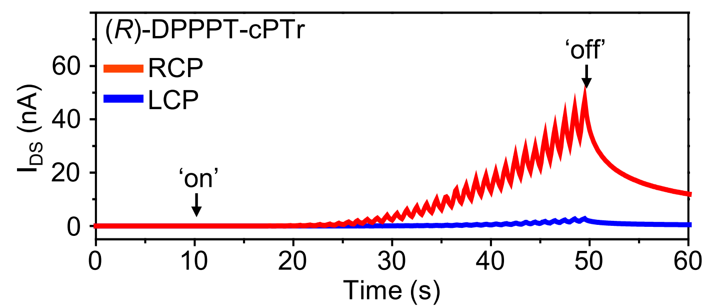
## Synaptic photodetector for direct CP light detection




**(S)-DPPPT or (R)-DPPPT**




⇒ **Synaptic photodetector for direct CP light detection was developed by depositing chiral organogelators onto IGZO phototransistor.**

⇒ **DPPPT-cPTr shows synaptic photoresponse, generating the accumulated photocurrent in response to the frequent CP light of target orientation only.**

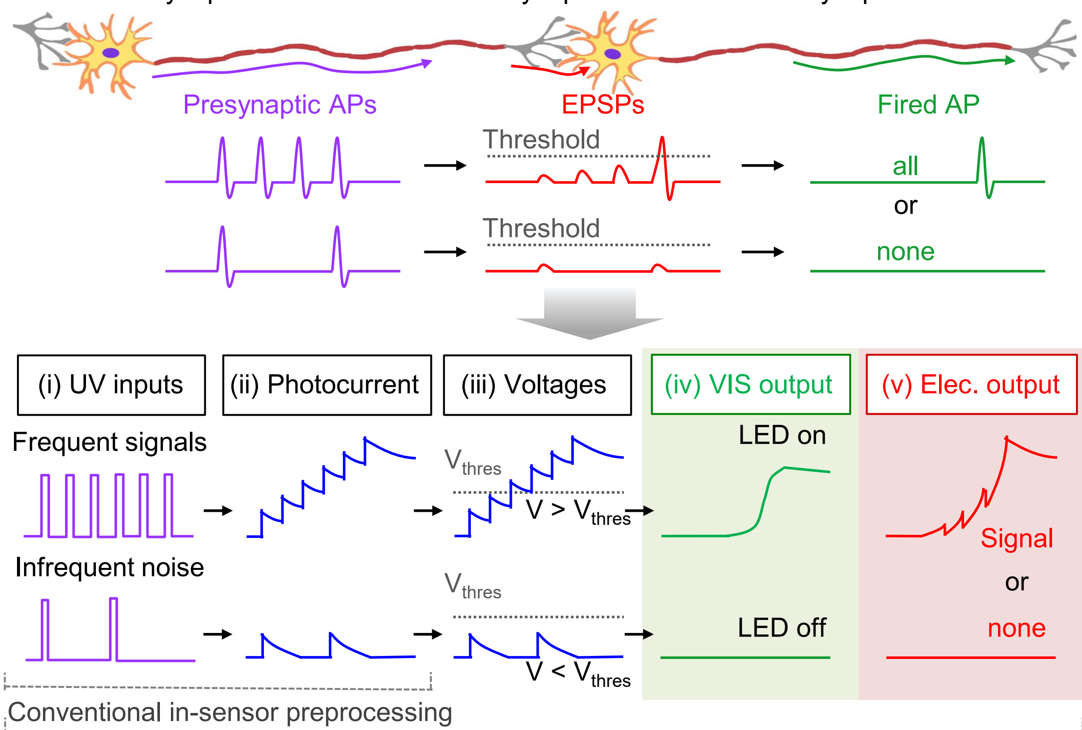


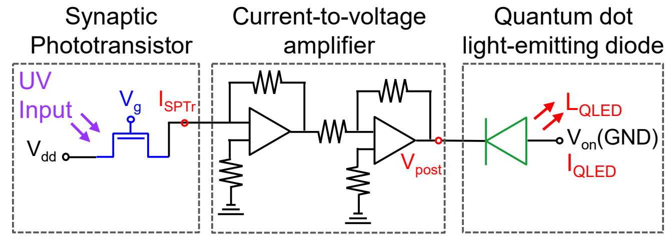
C. Choi *et al.* *Adv Sci.* 2304039 (2023)

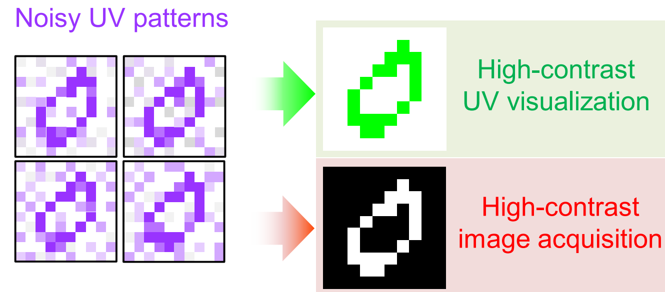
# All-or-None potentiation of synapse



## Integrated device inspired by all-or-none potentiation of human synapse




⇒ **All-or-none potentiation as well as synaptic plasticity realized by integrating the synaptic phototransistors and quantum-dot light-emitting diodes (QLED).**

⇒ **SPTr with photon-triggered synaptic plasticity & QLED with threshold switching characteristics enable "Signal-or-None (SoN) on-device preprocessing".**

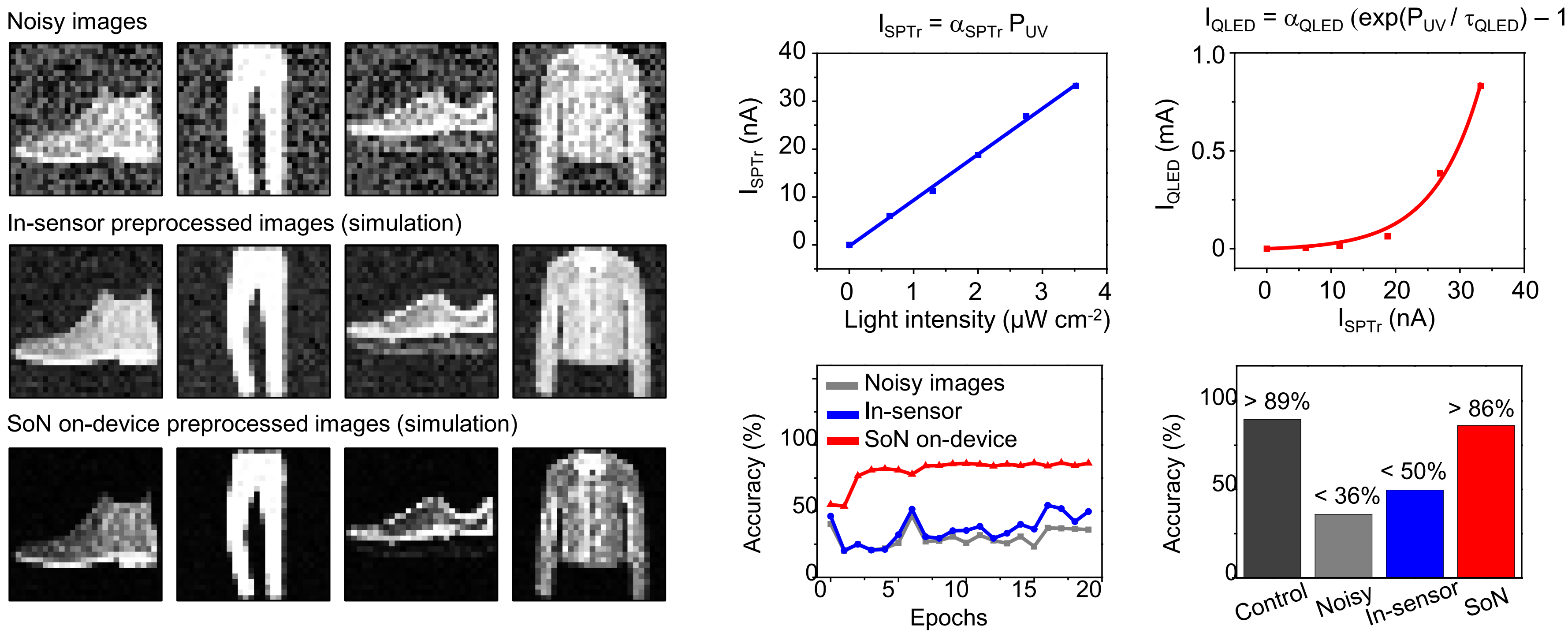


C. Choi *et al.* *Sci. Adv.* **8**, *eabq3101* (2022)

# Improvement in image recognition



## Improvement in image recognition based on deep neural network




⇒ **Simulated images (preprocessed images and SoN preprocessed images) were prepared from noisy images using the empirically fitted parameters.**

⇒ **Recognition rate of such images were evaluated using ResNet50 trained with standard training dataset.**

⇒ **SoN preprocessing significantly improve the image recognition because of significant reduction of background noise.**



C. Choi *et al.* *Sci. Adv.* **8**, *eabq3101* (2022)

# Acknowledgment

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## Group Members


## Collaborators

Prof. Dae-Hyeong Kim (SNU)
Prof. Donhee Ham (Harvard)
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Prof. SungWoo Nam (UC Irvine)
Prof. Young Min Song (GIST)
Prof. Taeghwan Hyeon (SNU)
Prof. Moon Kee Choi (UNIST)
Dr. Do Kyung Hwang (KIST)

NRF 한국연구재단

# Thank you

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