Is a neuron worth a thousand pixels?

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Outline

- Sparsity in the Visual System
- Compressive Sensing
- An Example: the Single-pixel Camera
Sparsity in the Visual System

Cones

Regular?

Random?

De Monasterio, 1981
Roorda, 1999
Sparsity in the Visual System

Natural Scenes

Throw away 88%

DCT

IDCT

difference
Sparsity in the Visual System

Learning Algorithms

- spatially localized
- oriented
- bandpass

Olshausen and Field, 1996
Sparsity in the Visual System
Receptive Fields

“These observations made in 1958 had not been predicted and came as a complete surprise” Hubel, 1995

Hubel and Wiesel, 1959, 1968
Sparsity in the Visual System

Learning Algorithms

Natural scenes

Sparsity constraint

Olshausen and Field, 1996
Sparsity in the Visual System

Development/Evolution

Pettigrew and Freeman, 1973
Sparsity of the Visual System

- Information-efficient coding of natural images
- Energy-efficient metabolism

Barlow, 1961
Quiroga, 2005
Compressive Sensing
Classical Paradigm

Number of measurements

\[ k \geq (2)B \]

Bandwidth

Measurement matrix \( N \times N \)
Compressive Sensing
New Paradigm

\[ y = \mathbf{K} \mathbf{x} \]

Number of measurements \( K \geq C S \log(N) \)

Sparsity

Measurement matrix \( \mathbf{K}^{\ast} \mathbf{N} \)
Compressive Sensing
Reconstruction

\[ s = \text{argmin} \|s'\|_1 \text{ s.t. } \Theta s' = y \]

\[ s = \text{argmin} \|s'\|_0 \text{ s.t. } \Theta s' = y \]

\[ s = \text{argmin} \|s'\|_2 \text{ s.t. } \Theta s' = y \]

(Donoho, 2006)

http://www.acm.caltech.edu/l1magic/
Compressive Sensing

- Accurate reconstruction of randomly undersampled ‘somewhere’ sparse signals
Single-pixel Camera

\[ \{y\} = \{x\} \]

http://www.dsp.ece.rice.edu/cscamera
**Single-pixel Camera**

Monochrome

- **Lens 1**
  - \( f = 0.08 \text{ m} \)
  - \( F = 4 \)

- **DMD 13.68*13.68 \text{ um}**
  - 1024*768

Optics of the DMD not simulated

- **Lens 2**
  - \( f = 0.1 \text{ m} \)
  - \( F = 4 \)

- **Photodiode**
  - 2.8*2.8 \text{ um},
  - integration time 0.101 \text{ s}
  - Geometric efficiency 85%
  - Digitization 12 bit

- **Illuminance**
  - 90

- **Digitization**
  - 12 bit

- **Monochrome**

- **Object**

- **Light**

- **DMD + ALP Board**

- **Lens 1**

- **Lens 2**

- **Photodiode**

- **Optics of the DMD not simulated**

http://www.dsp.ece.rice.edu/cscamera
\( \phi \)

Gaussian

Hadamard (the one Rice used)

Random Bernoulli

Random sparse (Berinde, 2008)
\[ N = 64 \times 64 = 4096 \]

\[ K = 800 \]

\[ K = 1600 \]

\[ K = 1024 \]
Single-pixel Camera

- Compressive Sensing (Compressed Sampling) shifts the technological burden from the sensor to processing.
Conclusions

- No trivial link between Compressive Sensing and the way the Visual System works.

- Compressive Sensing is not just a measurement paradigm. It provides a broader framework.
  - Proof of existence and unicity
  - Plausible alternatives to \n  - Extension to deterministic or dynamics settings?
Thank you!