Shoot to kill

Spatial light modulators to activate small neural populations simultaneously

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4th April 2014

Gatsby tea talk

Order of Business

1. The Experiment
2. The Optics
3. The Problems

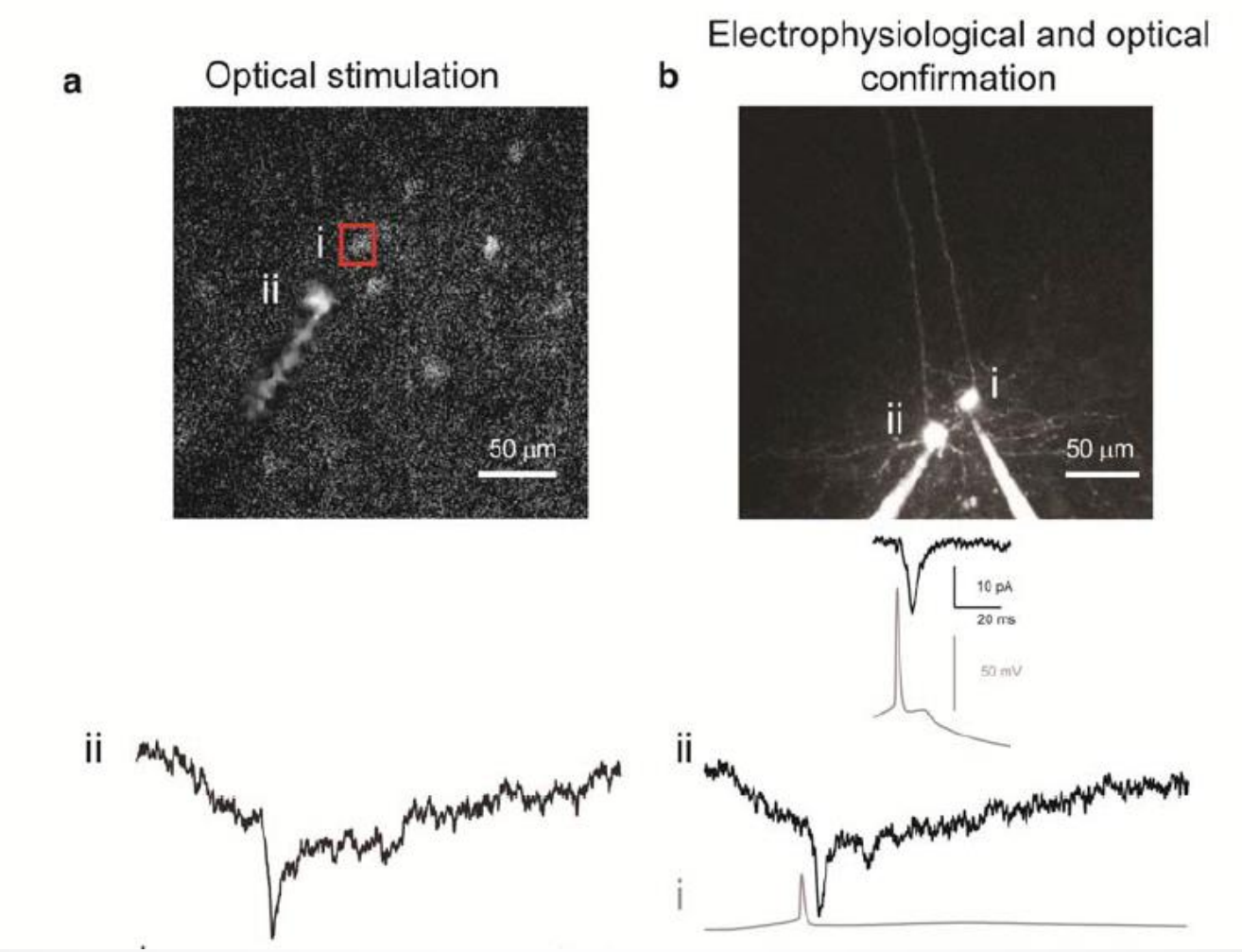
4. The Solution?

The Experiment

Activate a subset of cortical neurons and record from many around to investigate neural circuits.

- Mice infected via adeno-associated virus with opsin ($C1V1_T$)
- Find affected neurons (e.g. virus co-expressing EYFP), choose targets for stimulation
- Simultaneously activate the target neurons (induce spikes)
- Record activity from neurons, see how the activation of the stimulated neurons affect the circuit.

The Experiment

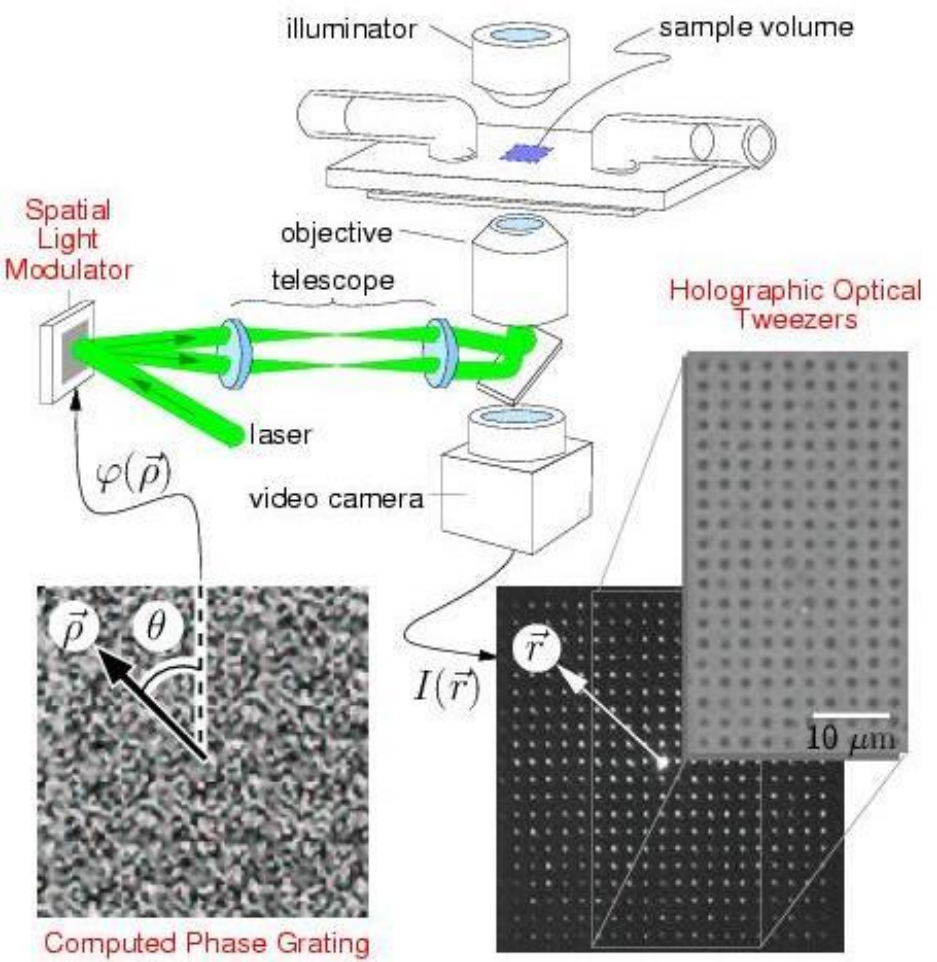


The Optics

Use spatial light modulators to split laser beam and create maxima at pre-specified locations

- Phase-only Spatial light modulators (PO-SLMs) consist of electronically addressable pixels that can create retardation of the incoming wavefront thus creating "arbitrary" phase-pattern in the SLM plane, which thereafter propagates to the far field and interferes with itself, creating the desired patterns.

The Optics


illuminator
sample volume
Spatial Light Modulator
objective
telescope
Holographic Optical Tweezers
laser
$\varphi(\vec{\rho})$
video camera
$\vec{\rho}$
θ
$\vec{r}$
$I(\vec{r})$
10 μm
Computed Phase Grating

The Optics

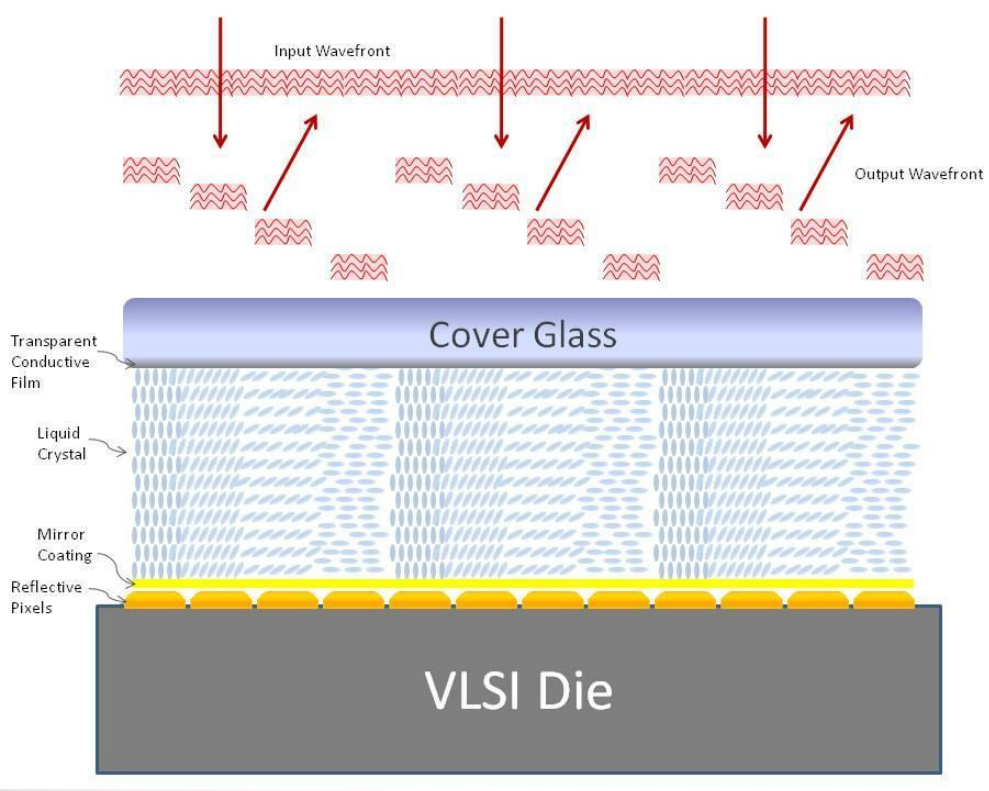
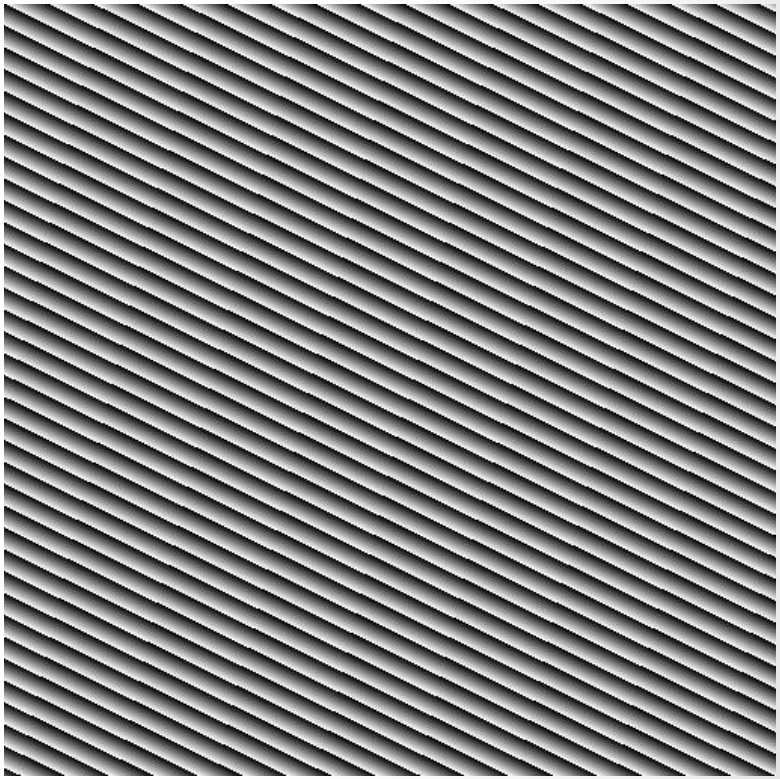


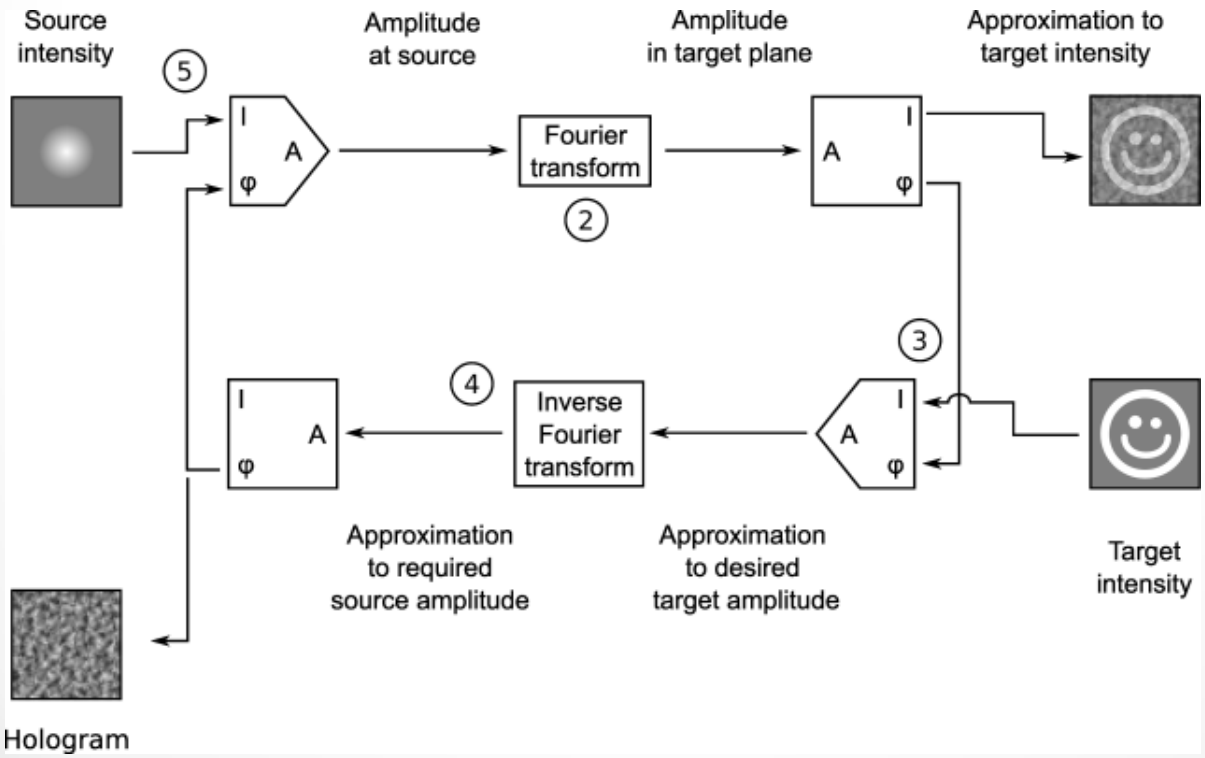
Figure 1. **Side view of an LCOS-SLM device. A wavefront entering the device is phase modulated by varying voltage on the individual pixels, which in turn rotates the LC molecules above the pixel.**



SLM pattern produced

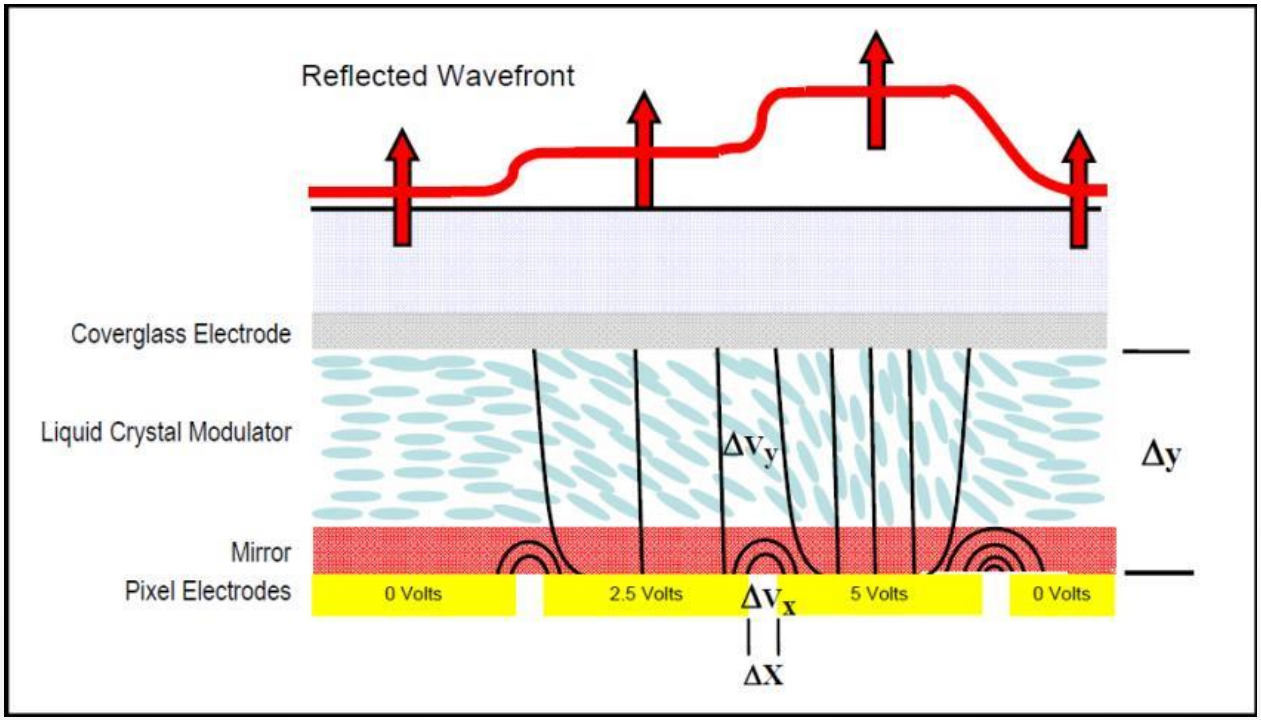
The Optics

- Gerchberg-Saxton (1972) algorithm to iteratively optimize SLM pattern



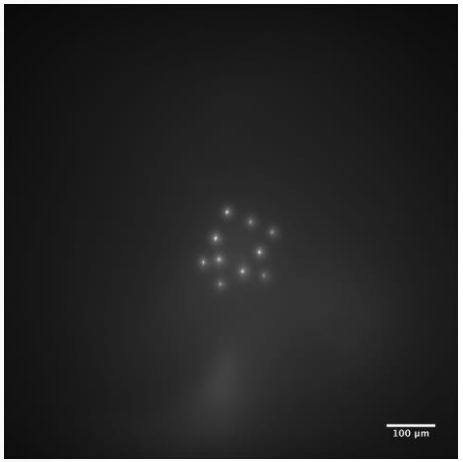
The Problems

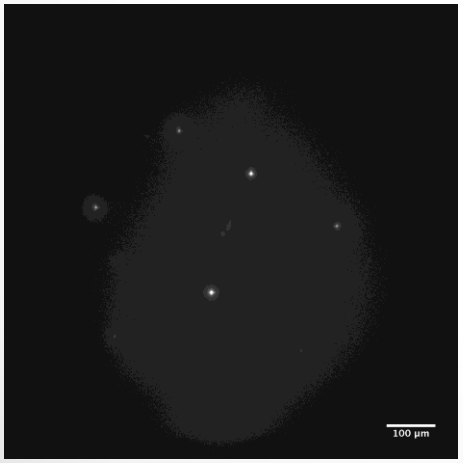
- Phase and pixel quantization
- wavefront correction
- inter-pixel crosstalk

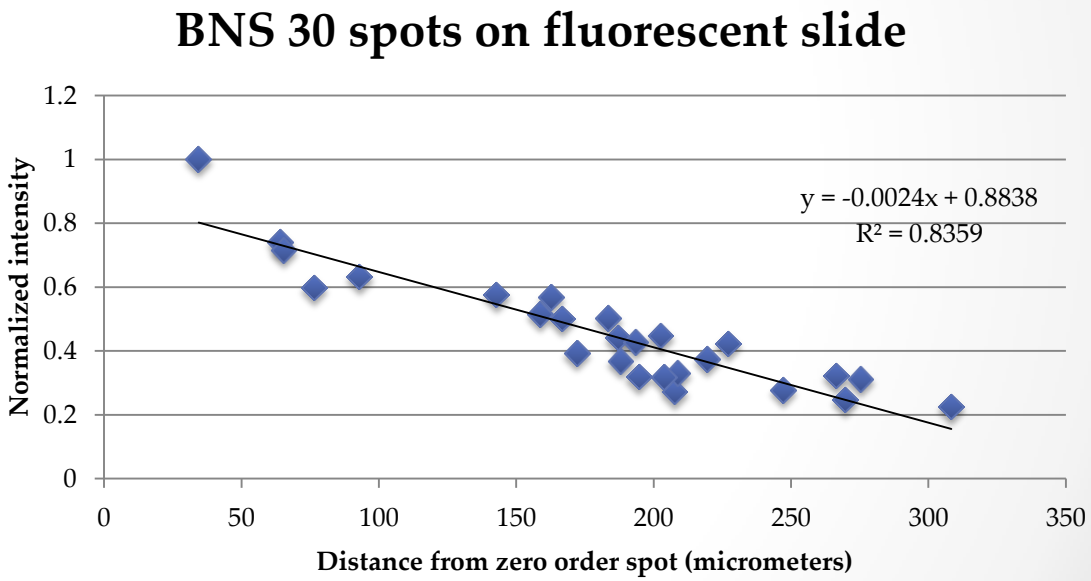


The Problems

- Tradeoff between field of view and power?







Machine Learning: The Solution?

- G-S algorithm -> optimal, but unconstrained solution
- Add constraints and project to find best solution?
  - Impossible, we cannot define all constraints.

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- Extremely cheap to collect data, ~30 ms to set new SLM pattern, BUT very high dimensional (maps from 512*512*256 to 512*512*256)
- Learn the much lower dimensional basis of SLM patterns that create spot-patterns in the far field
- In this representation, learn the association between SLM and far field patterns
- Predict good SLM patterns for desired far field ones

Today's Recipe

- Take a bit of a neuroscience dream experiment, that is coming true
- Add cool laser physics stuff
- Spice it up with machine learning to solve what physics can not

- Let everyone have tea and biscuits

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References

- Spatial Light Modulator Microscopy (Nikolenko et al, 2013, CSH, Yuste lab)
- Targeting neurons and photons for optogenetics (Packer et al, 2013, Häusser lab)
- Two-photon optogenetics of dendritic spines and neural circuits (Packer et al, 2010, Yuste lab)
- Synthesis of Three-Dimensional Light Fields and Applications (Piestun & Shamir, 2002)