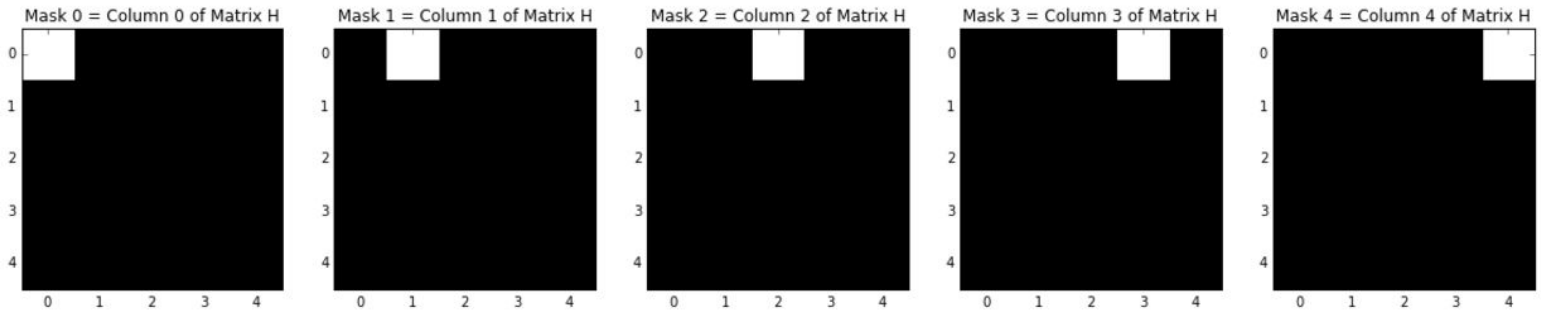
EECS16A Imaging 3

TA, ASE, ASE, ASE

Announcements

- Scheduling
  - If you don’t get this lab completed/checked off today, you can get it checked off at the beginning of Touch 1 in two weeks
- Everyone - log off and restart

Last time: Single-pixel scanning



- Setup a masking matrix where each row is a mask
  - Measured each pixel individually once

Last time: Matrix-vector multiplication

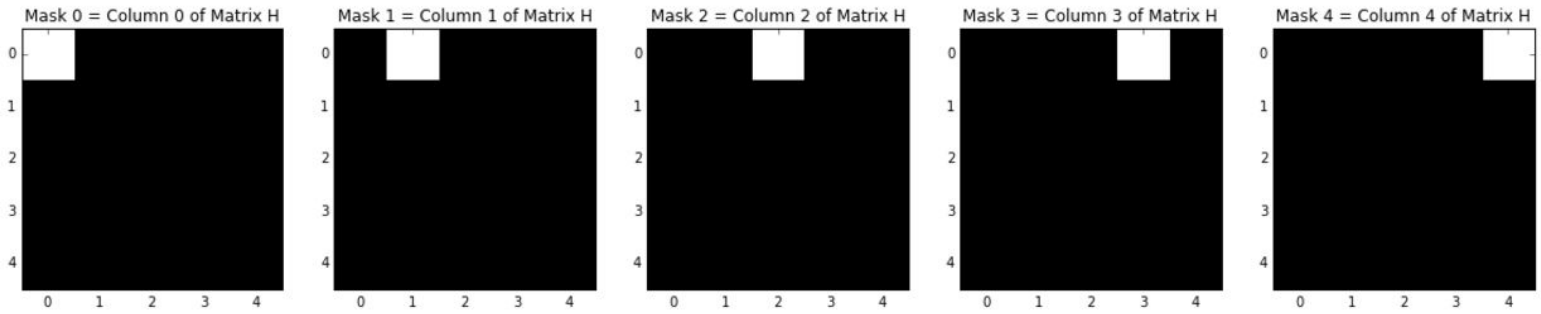
$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & \cdots \\ \cdots & & & & & & & & \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ \\ \\ \\ \\ i_n \end{bmatrix} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ \\ \\ \\ \\ s_n \end{bmatrix}$$

Masking Matrix H

Unknown, vectorized image, $\vec{i}$

Recorded Sensor readings, $\vec{s}$

Last time: Single-pixel scanning



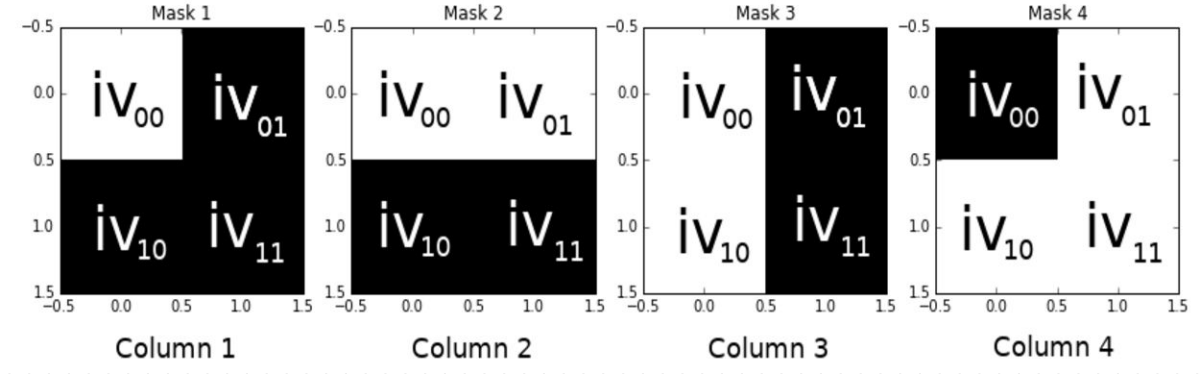
- Setup a masking matrix where each row is a mask
  - Measured each pixel individually once
- **How can we reconstruct our scanned image?**
- **What are the requirements of our masking matrix H?**

$$\vec{s} = H\vec{i}$$

Questions from last time

- Are all invertible matrices equally good as scanning matrices?
- What happens if we mess up a single scan?

Today: Multi-pixel scanning



- **Can we measure multiple pixels at a time?**
  - Measurements are now linear combinations of pixels
- **How can we reconstruct our scanned image? Why?**
  - There are still other things to be concerned about

Why do we care?

- We want to improve the quality of our images
- ‘Codes Revisited’ homework problem
- Redundancy is always good
  - Averaging measurements is better than using bad measurement values

How do we do it?

- We need to change our masks to improve our SNR (signal to noise ratio)
  - Take smarter measurements
  - Measure linear combinations of pixels instead of a single pixel
  - Redundancy is key to getting good results
- Problems?
  - Our measurements are noisy
    - What is noise?
  - Noise can be amplified through inverting a matrix
    - How?

What is noise?

0
1
2
.
.
.
10

Suppose we expect this from our sensor

But instead we get this

0.4
0.95
2.1
.
.
.
9.8

What is Noise?

We can say that this vector is the ideal vector plus some vector of disturbances we call “noise,” represented by ω

$$\begin{bmatrix} 0.4 \\ 0.95 \\ 2.1 \\ . \\ . \\ . \\ 9.8 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 2 \\ . \\ . \\ . \\ 10 \end{bmatrix} + \begin{bmatrix} 0.4 \\ -0.05 \\ 0.1 \\ . \\ . \\ . \\ -0.2 \end{bmatrix}$$

$\vec{s}_{real}$ $\quad$ $\vec{s}_{ideal}$ $\quad$ $\vec{w}$

What is noise?

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \cdots \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \cdots \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdots \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \cdots \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & \cdots \\
\cdots
\end{bmatrix}
\begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ \\ \\ \\ \\ i_n \end{bmatrix}
+
\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \\ \\ \\ \\ \omega_n \end{bmatrix}
=
\begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ \\ \\ \\ \\ s_n \end{bmatrix}
$$

Masking Matrix **H**

Unknown, vectorized image, $\vec{i}$

Random noise vector, $\vec{w}$

Recorded Sensor readings, $\vec{s}$

A more realistic system

- Sensor readings =
  image vectors applied to H + noise vector

$$\vec{s} = H\vec{i} + \vec{w}$$

- We can't reconstruct **i**, but we can estimate it

$$\vec{i}_{est} = H^{-1}\vec{s} = \vec{i} + \boxed{H^{-1}\vec{w}}$$

We have to be careful about this term or else it could blow up !!

The missing link

- H Is an NxN matrix that we know is linearly independent (invertible).
  Therefore: No eigenvalue = 0 and we can recover i with no noise
- H has eigenvalues $\lambda_1, \lambda_2, \ldots \lambda_n$
- Assume H has N linearly independent eigenvectors
- N lin. ind. vectors can span $\mathbb{R}^N$
  - They span the noise vector
  - The inverse has eigenvalues (as proven in homework) $\frac{1}{\lambda_1}, \frac{1}{\lambda_2}, \ldots \frac{1}{\lambda_n}$

The missing link

The noise term from before can be written as:

$$\vec{\omega} = \alpha_1 \overrightarrow{v_1} + \alpha_2 \overrightarrow{v_2} + \cdots \alpha_n \overrightarrow{v_n}$$

And:

$$H^{-1}\vec{\omega} = H^{-1}(\alpha_1 \overrightarrow{v_1} + \alpha_2 \overrightarrow{v_2} + \cdots \alpha_n \overrightarrow{v_n})$$

Finally

$$= \frac{1}{\lambda_1}\alpha_1 \overrightarrow{v_1} + \frac{1}{\lambda_2}\alpha_2 \overrightarrow{v_2} + \cdots \frac{1}{\lambda_n}\alpha_n \overrightarrow{v_n}$$

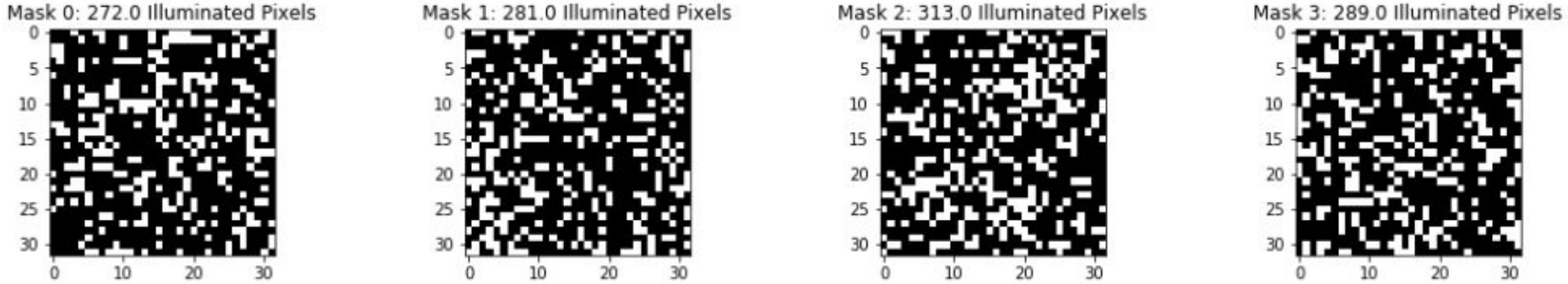
Linking it all together

$$\vec{i}_{est} = H^{-1}\vec{s} + \boxed{H^{-1}\vec{\omega}}$$

$$\boxed{H^{-1}\vec{\omega}} = \frac{1}{\lambda_1}\alpha_1\overrightarrow{v_1} + \frac{1}{\lambda_2}\alpha_2\overrightarrow{v_2} + \cdots \frac{1}{\lambda_n}\alpha_n\overrightarrow{v_n}$$

- The noise is directly related to the eigenvalues.
- We don't know what the alphas are, but we can reduce noise by choosing good eigenvalues
  - **What are good eigenvalues?**
- **What properties would a good H matrix have?**

Possible Scanning Matrix: Random



- Illuminate ~300 pixels per scan
  - *Usually* invertible
  - But what are its eigenvalues?

¯_(ツ)_/¯

A more systematic scanning matrix:

- Hadamard matrix!
- Constructed to have large eigenvalues
  - Just what we need!

Notes

- READ CAREFULLY - Long lab with lots of reading; heavily tests understanding of eigen-stuff
- Post check-off section is optional but very cool
- Can adjust projector settings
  - Focus with dial on side
  - Brightness, contrast, sharpness

Debugging

1. Make sure wires/resistors/light sensor are not loose
2. Light sensor orientation: short leg goes into +
3. Check COM Port
4. Reupload code to launchpad after making any change in circuit
5. Check Baud Rate in Serial Monitor (115200)
6. Projector might randomly restart in the middle of the lab. Make sure brightness 0 contrast 100.
7. Cover box with jacket for dark scanning conditions
8. If you see a very bright corner in the scan, move the light sensor away from the projector