Soft Decision Channel Optimized Vector Quantization

Introduction

- Our goal is to improve multimedia data transmission over noisy channels
- i.e. sending digital photos between cell phones
  - Low power, low bandwidth

Last Year

- Extending work done previously by Andrew MacDonald, Sean Noble, and Dave Richardson
- Implemented COVQ over a Rayleigh fading channel

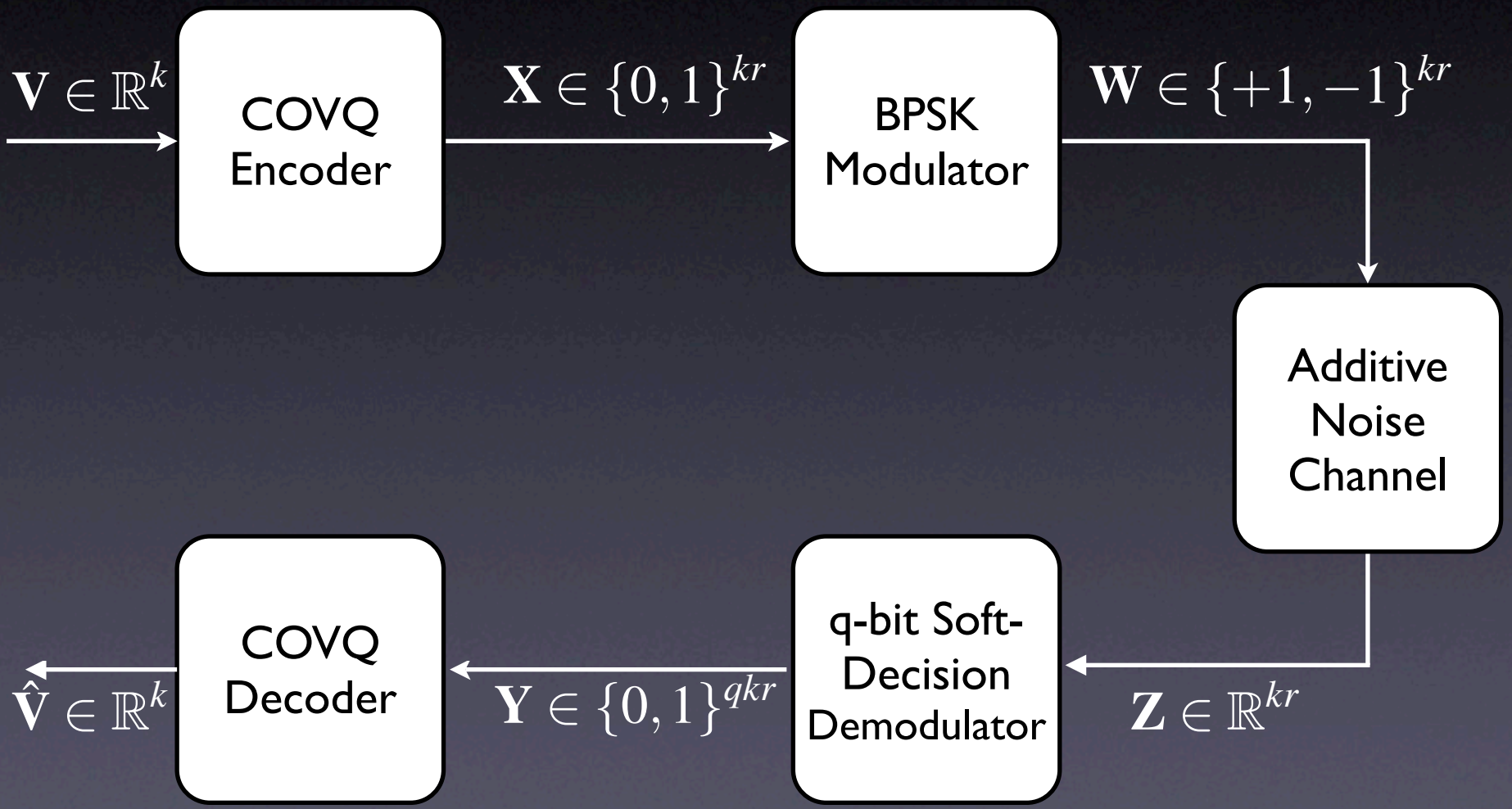
This Year

- Add *soft decision* to the system
- Changes were required in both training and transmission

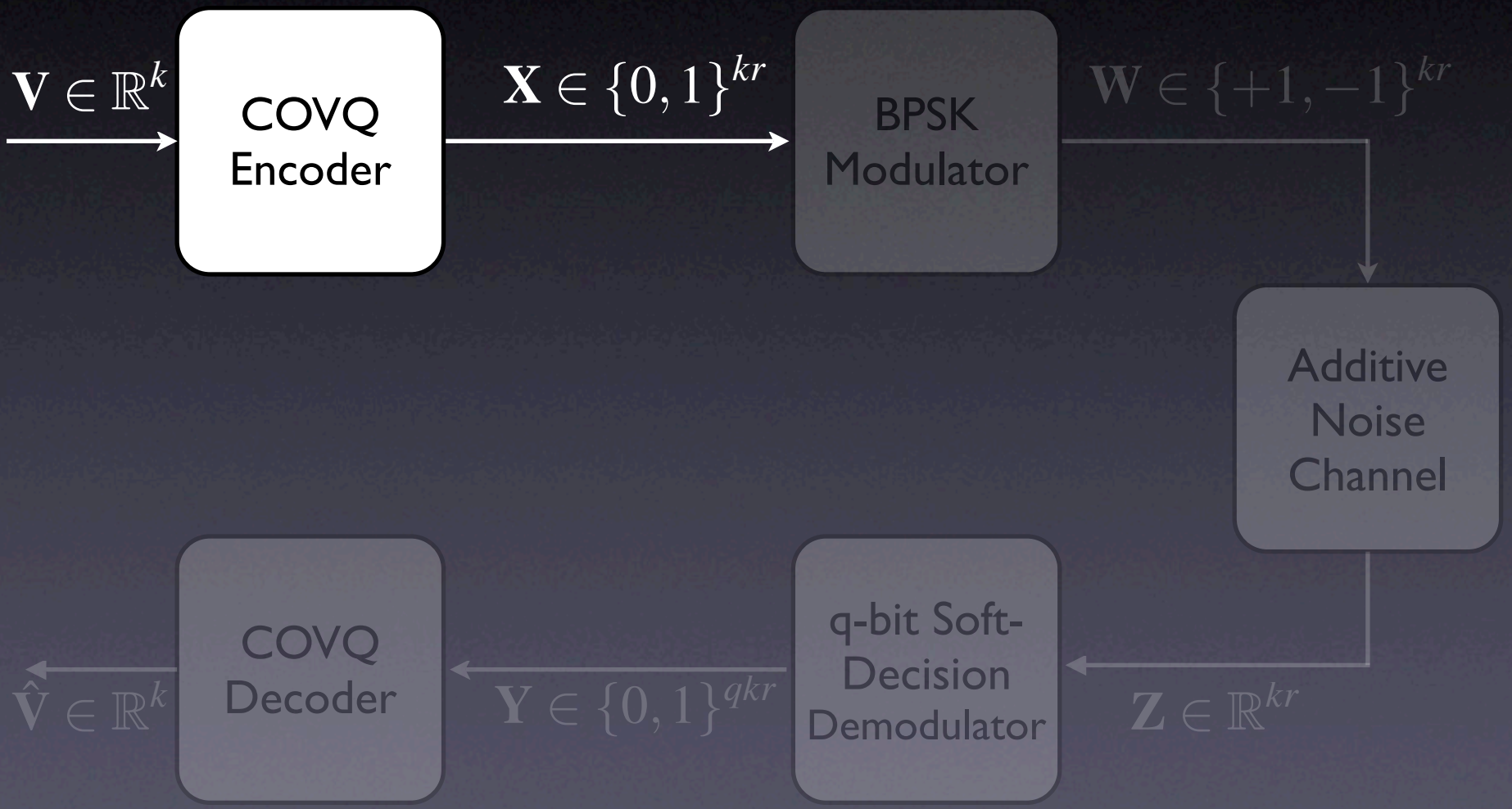
Concepts

- Channel Optimized Vector Quantization
- LGB Algorithm
- Soft Decision

Concepts - COVQ



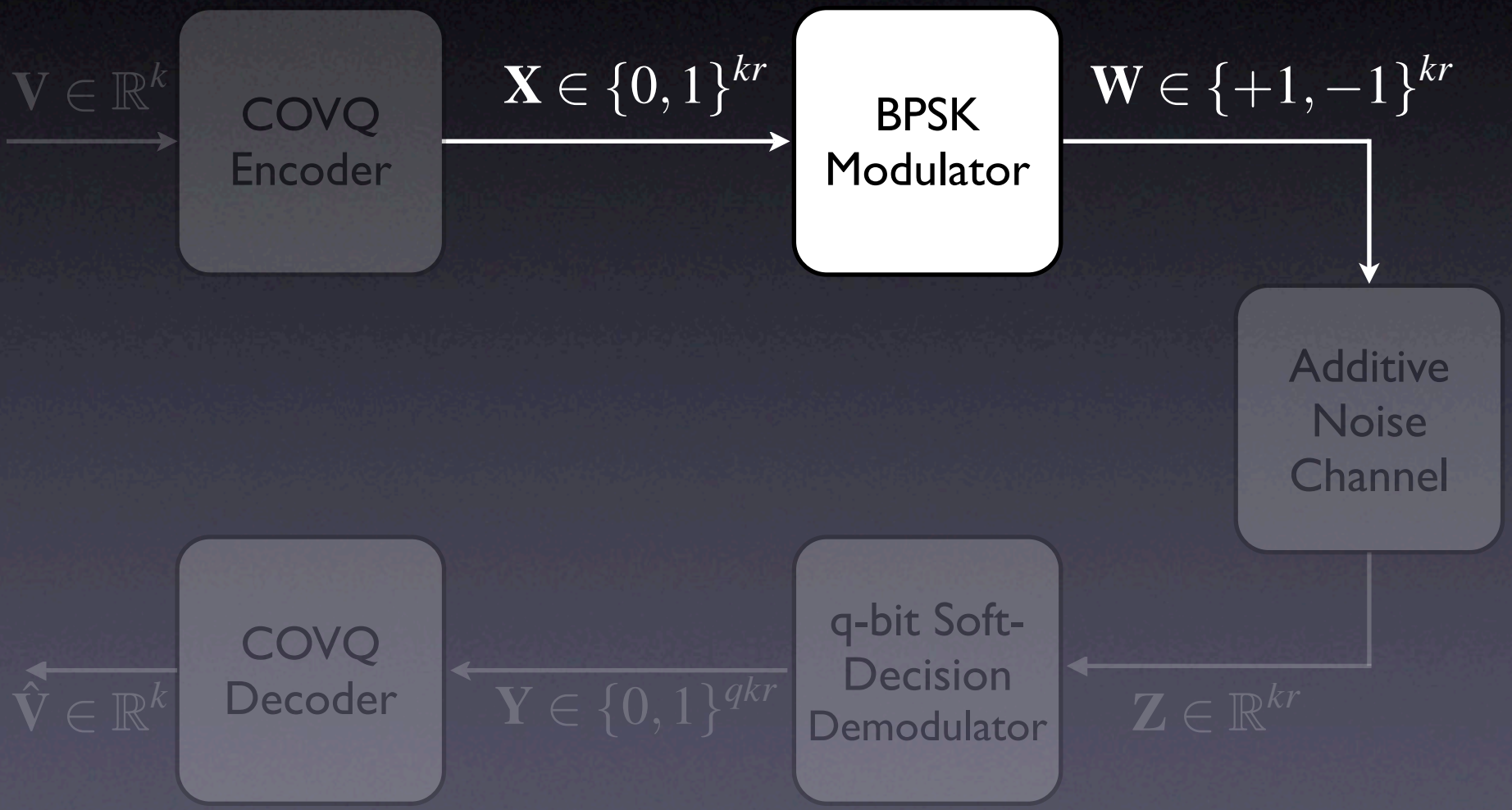
Concepts - COVQ



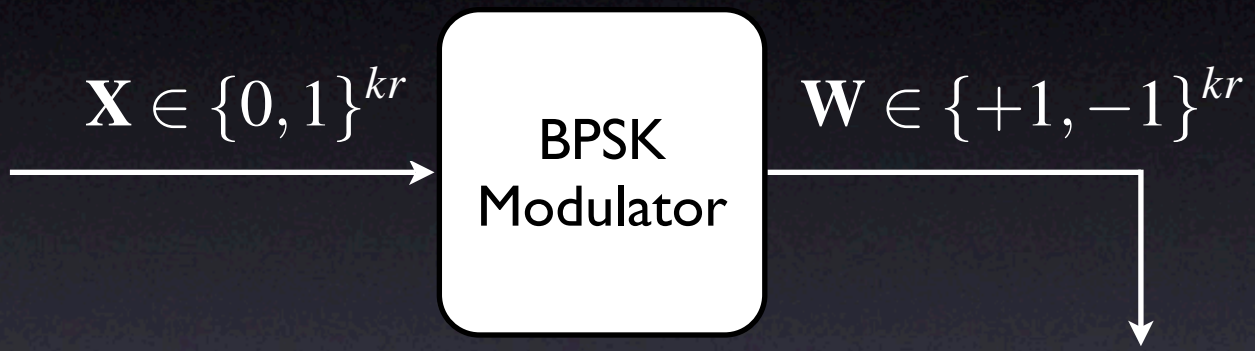
Concepts - COVQ

- A quantizer: takes k real valued numbers as a vector and represents that vector by an index
- That index is between 0 and $2^{kr} - 1$ which can be represented by kr bits

Concepts - COVQ

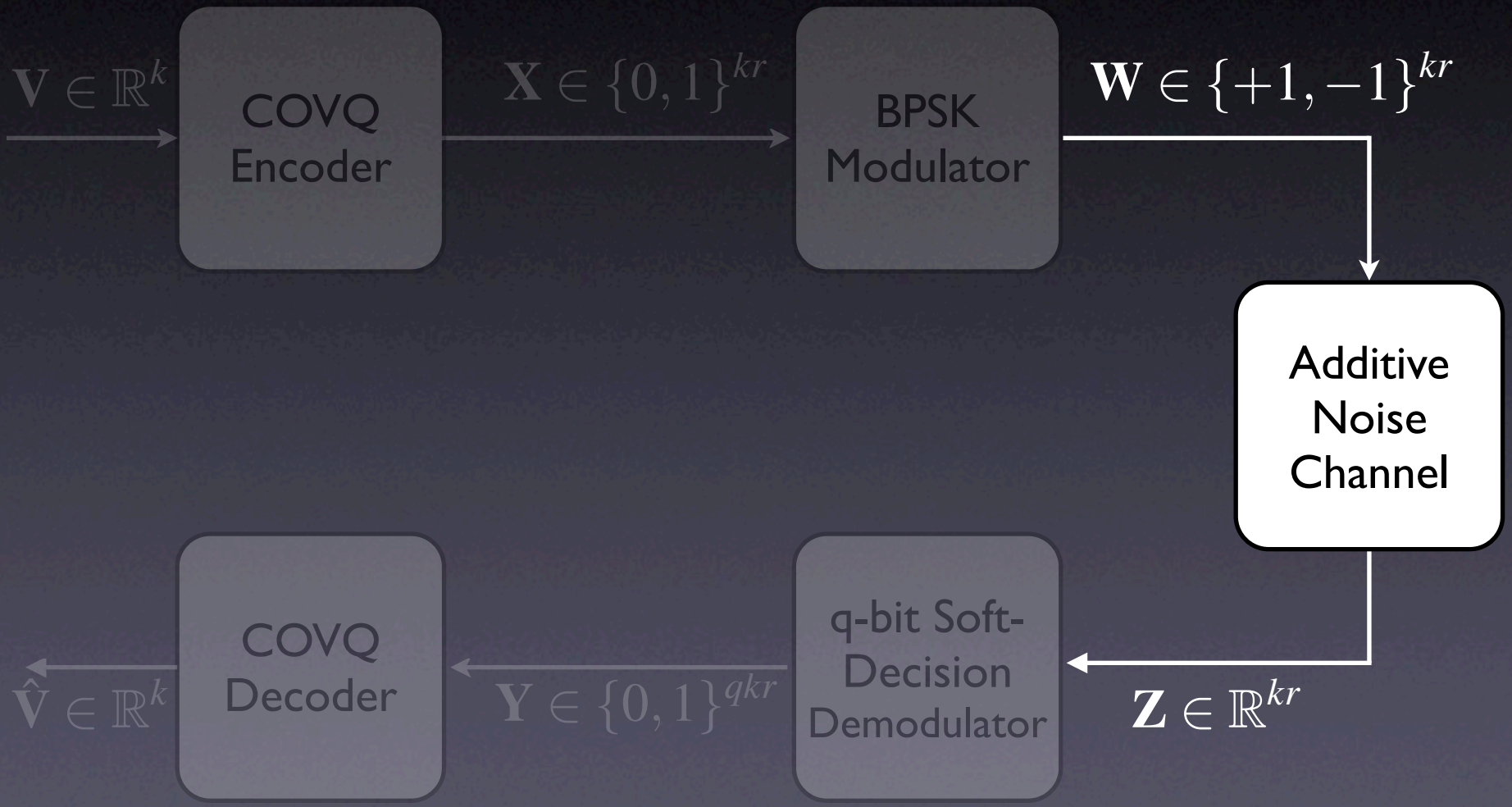


Concepts - COVQ



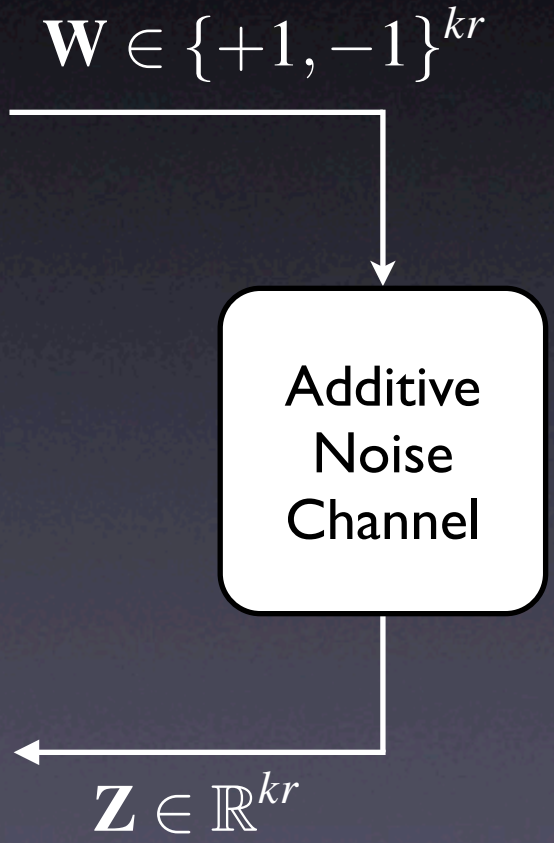
- Takes the kr bits representing our index and *modulates* them
- 0 is modulated to a -1
- 1 is modulated to a +1

Concepts - COVQ



Concepts - COVQ

- One "bit" at a time is sent over the channel
- This happens kr times for each vector
- Each bit sent is transformed by the channel through the *addition of noise*

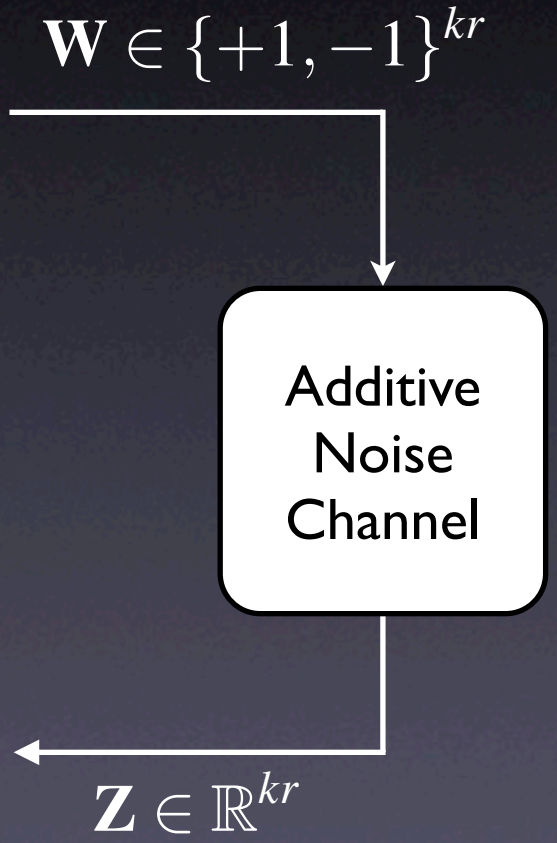


Concepts - COVQ

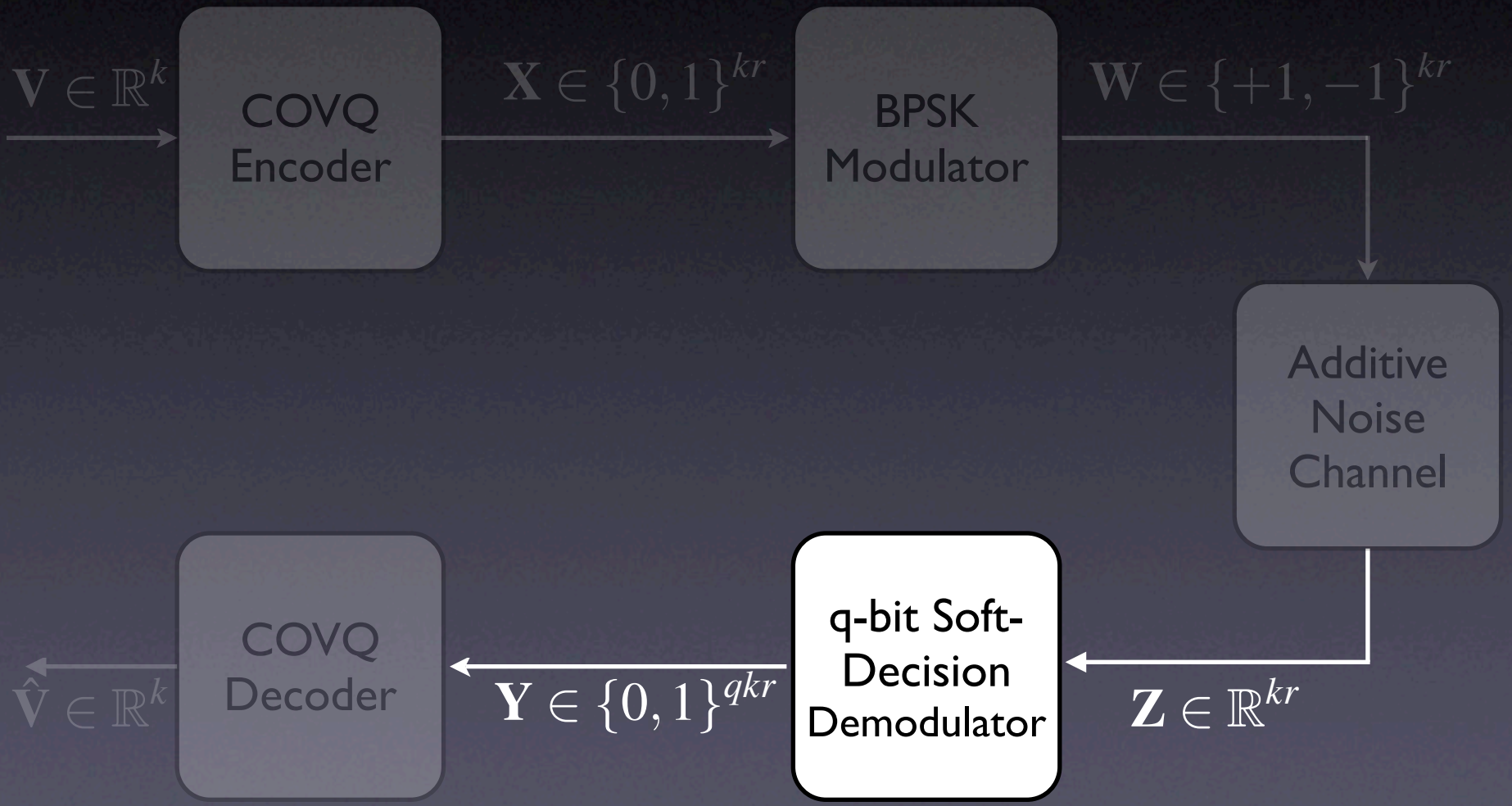
- Additive noise means each signal has some random noise added to it
- For each of the kr bits we have :

  $z_i = w_i + n_i$

  where n_i is a zero mean Gaussian random variable

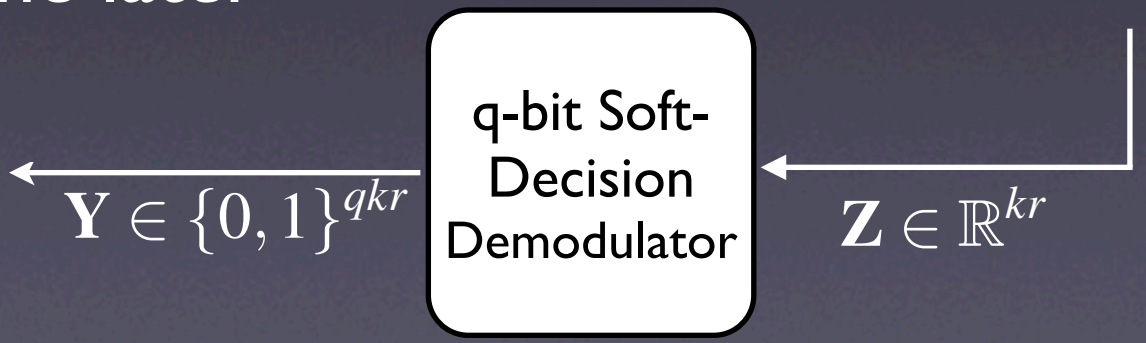


Concepts - COVQ

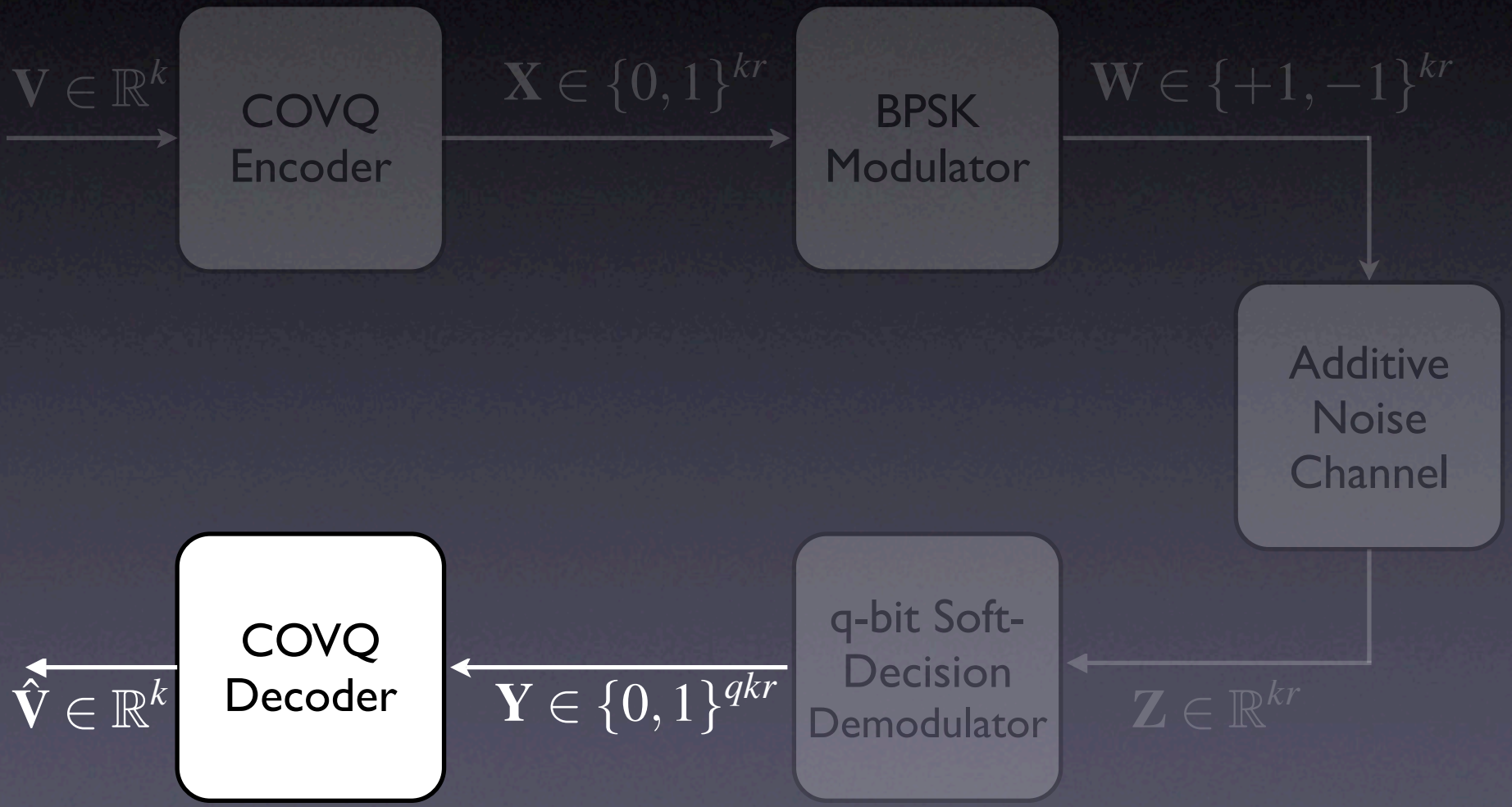


Concepts - COVQ

- For each kr-bit vector sent over the channel, we receive kr real values
- Each of these kr real values are quantized using a uniform quantizer with 2^q levels
- This is the key addition over last year's project, more to come later

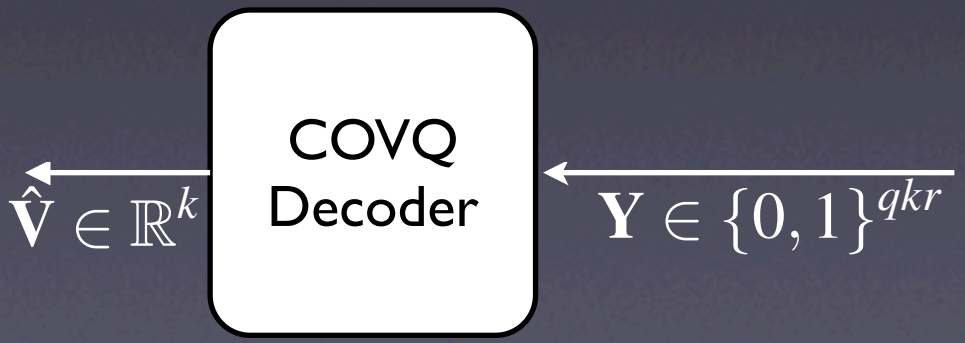


Concepts - COVQ



Concepts - COVQ

- Using a simple lookup table, the index (represented by the qkr bit string $\mathbf{Y}$) produces an output vector $\hat{\mathbf{V}}$



Concepts - LBG

- The LBG algorithm trains a codebook for a given set of test data.
- The codebook is a set of quantization levels, that can be made arbitrarily close to the optimal set of quantization levels.
- The encoder then choses appropriate indices from a codebook to send over the channel.

Codebook Training

- When training a codebook, the LBG algorithm needs to know how many quantization levels to store.
- The codebook will have less distortion if the training data is a better representation of the data that will eventually be used.
- For this reason the codebooks are trained using training data taken from a set of images.

Quantization Scenarios

- Our initial LBG algorithm would create a Vector Quantization (VQ) codebook.
- VQ allows for input samples to be grouped in vectors of the size desired, we refer to this as dimension.

Quantization Scenarios

- Distortion can be minimized again by incorporating Channel Optimized Vector Quantization (COVQ) into LBG.
- COVQ choses the quantization levels incorporating the channel behaviour.
- This will provide smaller distortion between the given training data (recovered after the channel) and the codebook.

Concepts -Soft Decision

- The main focus of this project is to incorporate soft decision decoding.
- In order to allow for soft decision decoding we must incorporate the extra quantization levels into the codebook.
- This means incorporating the soft decision levels into the LBG algorithm.

Soft Decision Decoding

- Hard decision occurs when a received bit over the channel is mapped to a '0' or '1', so a bit sent over the channel is received as a bit.
- The idea behind soft decisions is that we have 2^q decision regions rather than just the '0' and '1' of hard decision decoding (q=1).

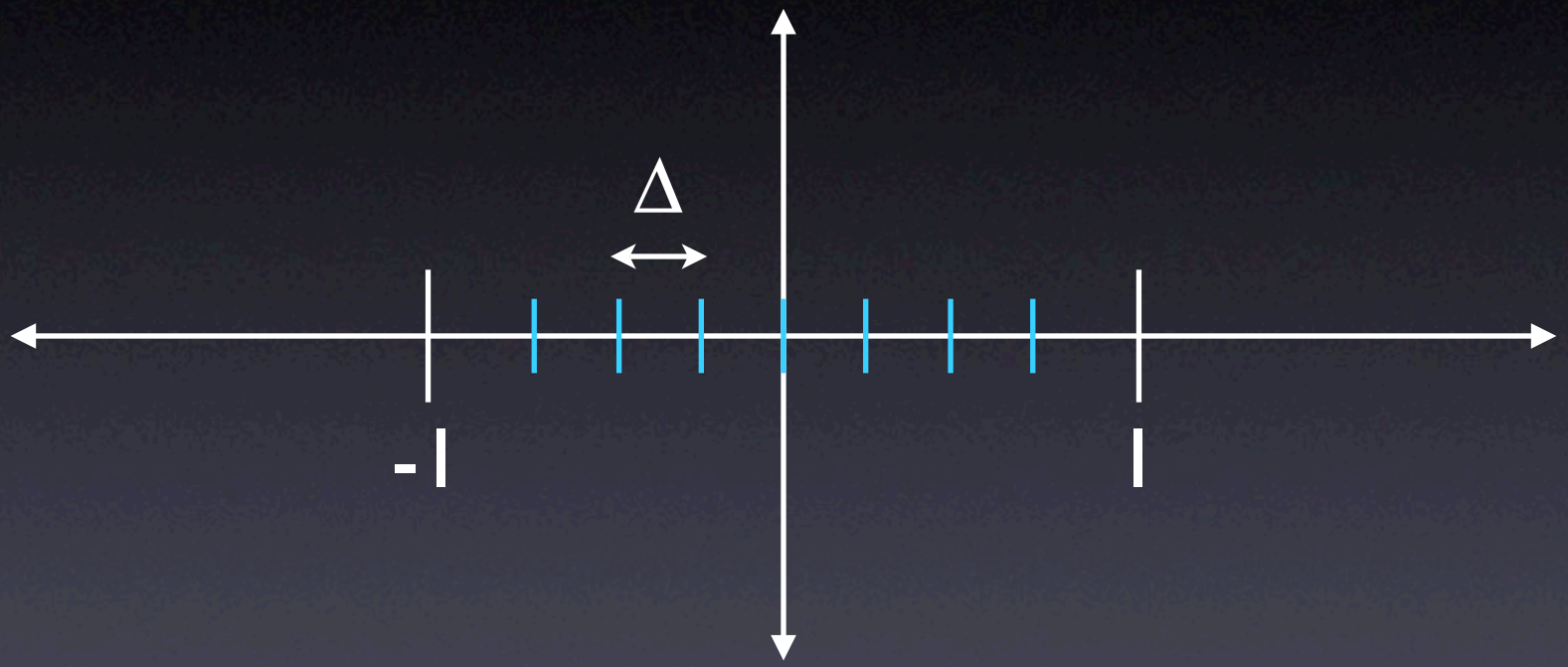
Soft Decision Decoding

- This means that a ‘1’ bit sent over the channel could be decoded as an intermediate value between ‘0’ and ‘1’.
- Now we must determine the size of these bins that will provide the lowest distortion measures while all else is constant.

Binary Subregions

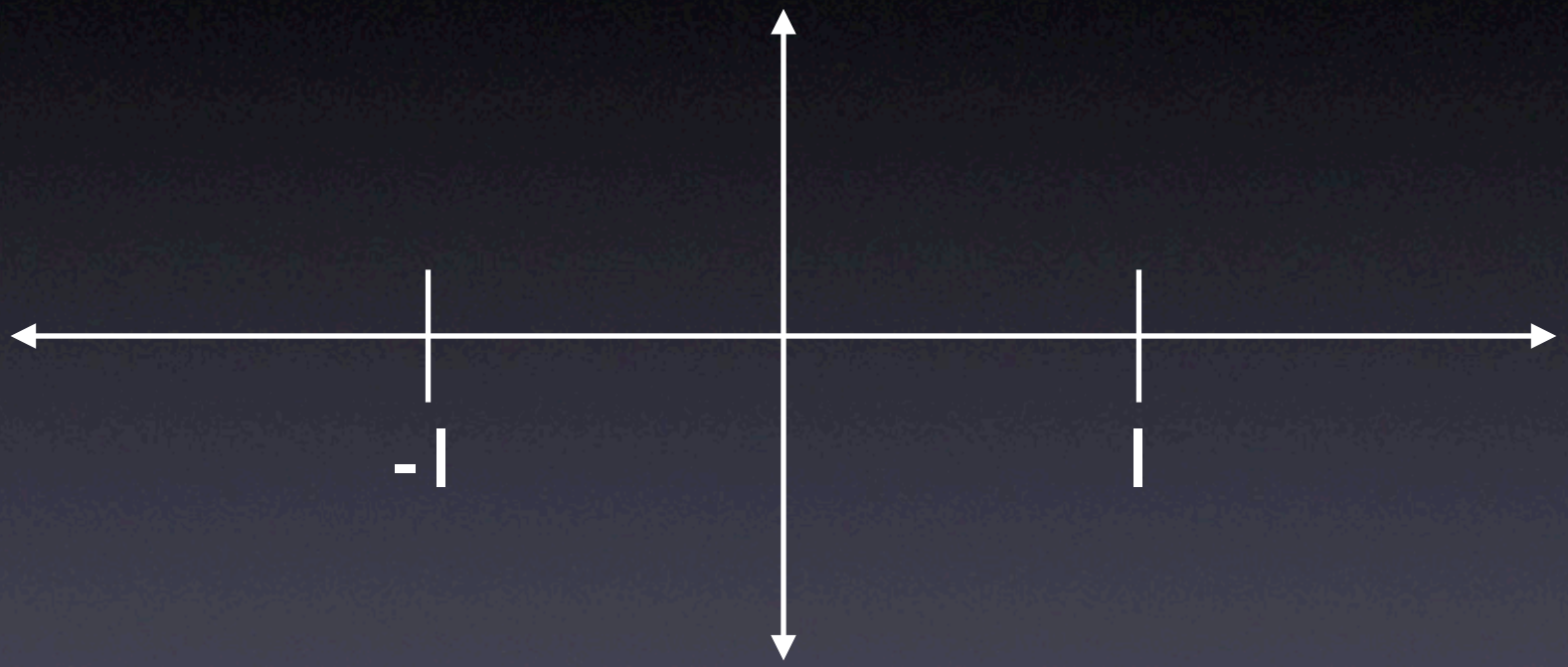
- It turns out that optimal bin sizes are available from previous Mathematics research.
- The number of bins is determined by q and the size of the bins is determined by CSNR.
- As the channel gets cleaner we are less likely to need the intermediate bins, thus the bins get smaller as CSNR increases.

Soft Decision Decoding



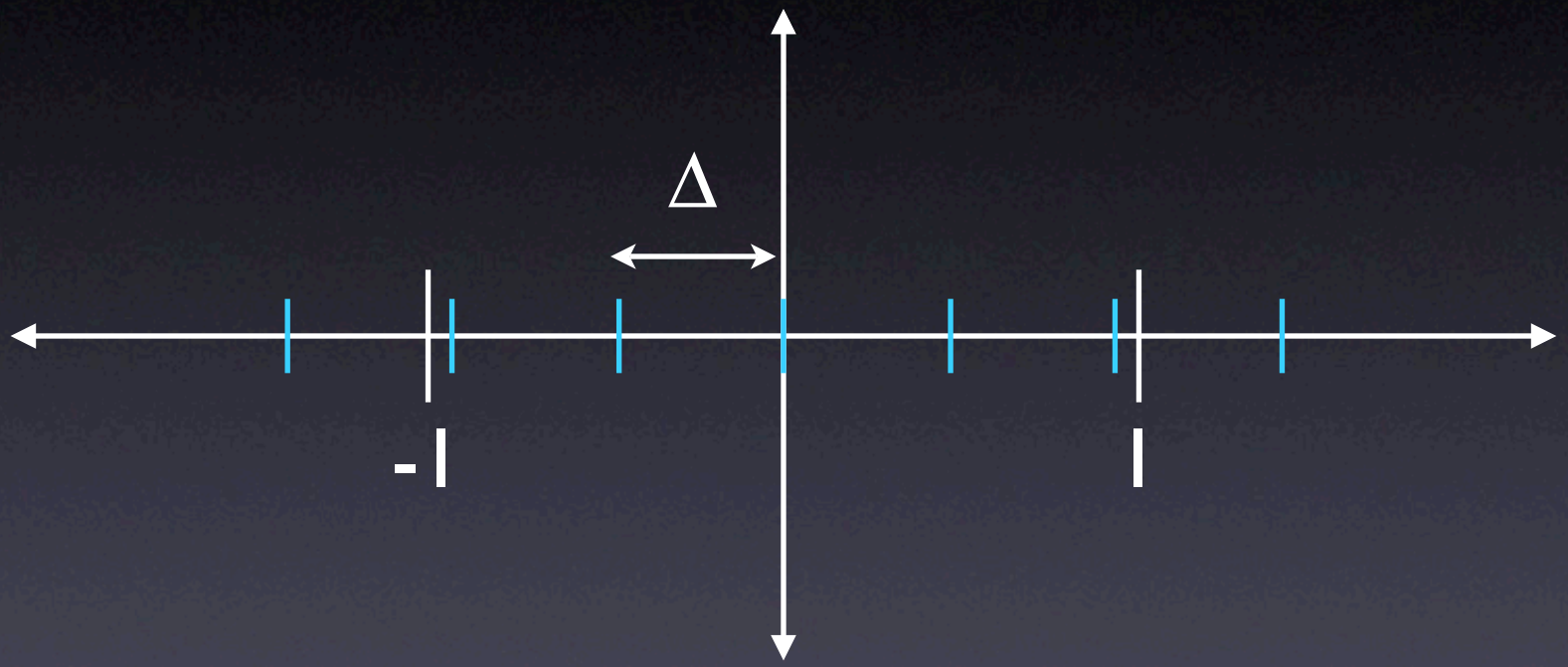
- example: q = 3 (8 bins), CSNR = 5, Δ = .2340

Soft Decision Decoding



- example: q = 3 (8 bins)

Soft Decision Decoding



- example: q = 3 (8 bins), CSNR = 0, Δ = .4815

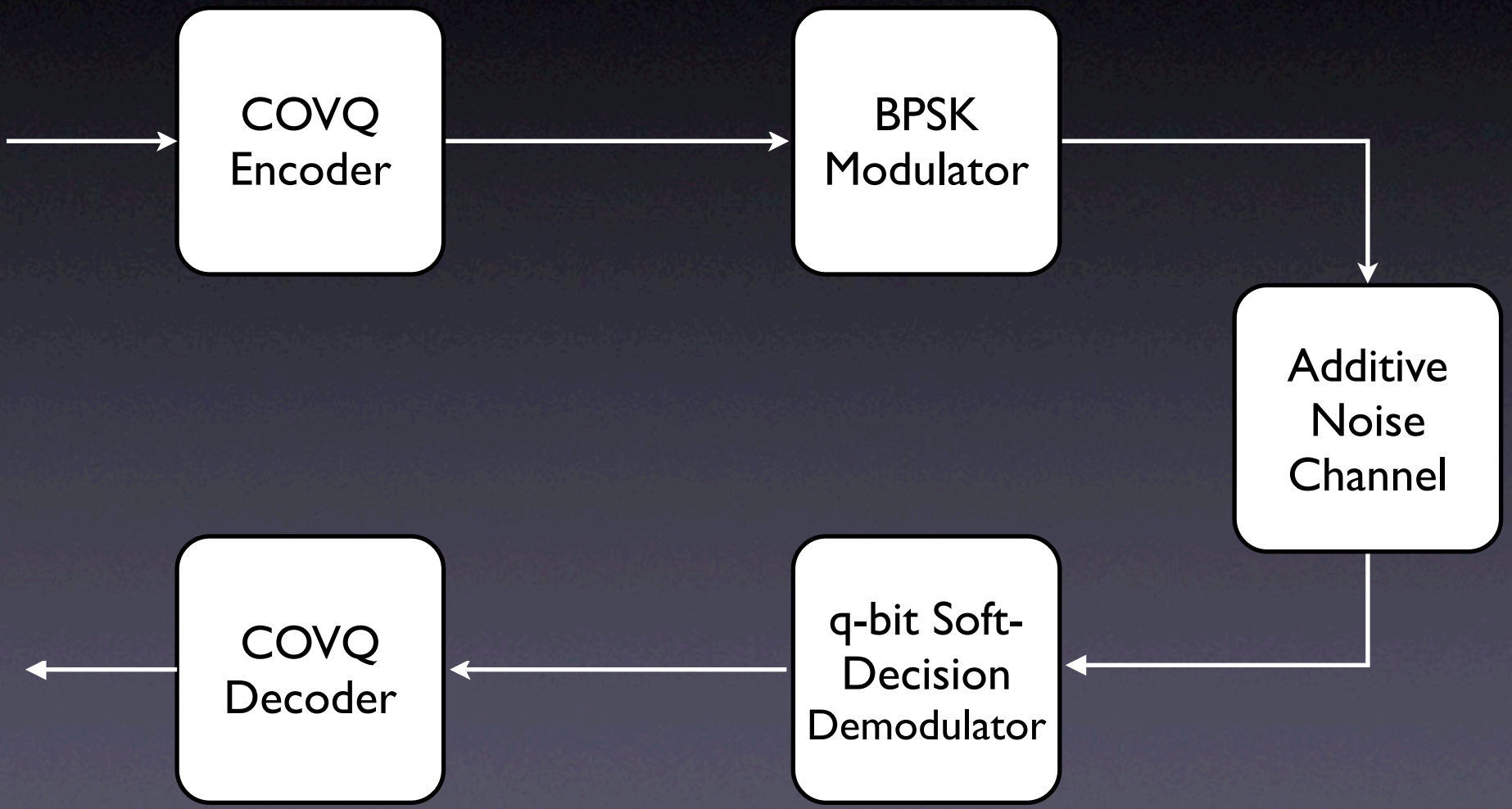
Concepts - Soft Decision

- We can see that for every bit sent over the channel we will decode into q bits.
- So initially we send indices of size kr bits across the channel, and we receive indices of size qkr bits (k = dim, r = rate/dim).

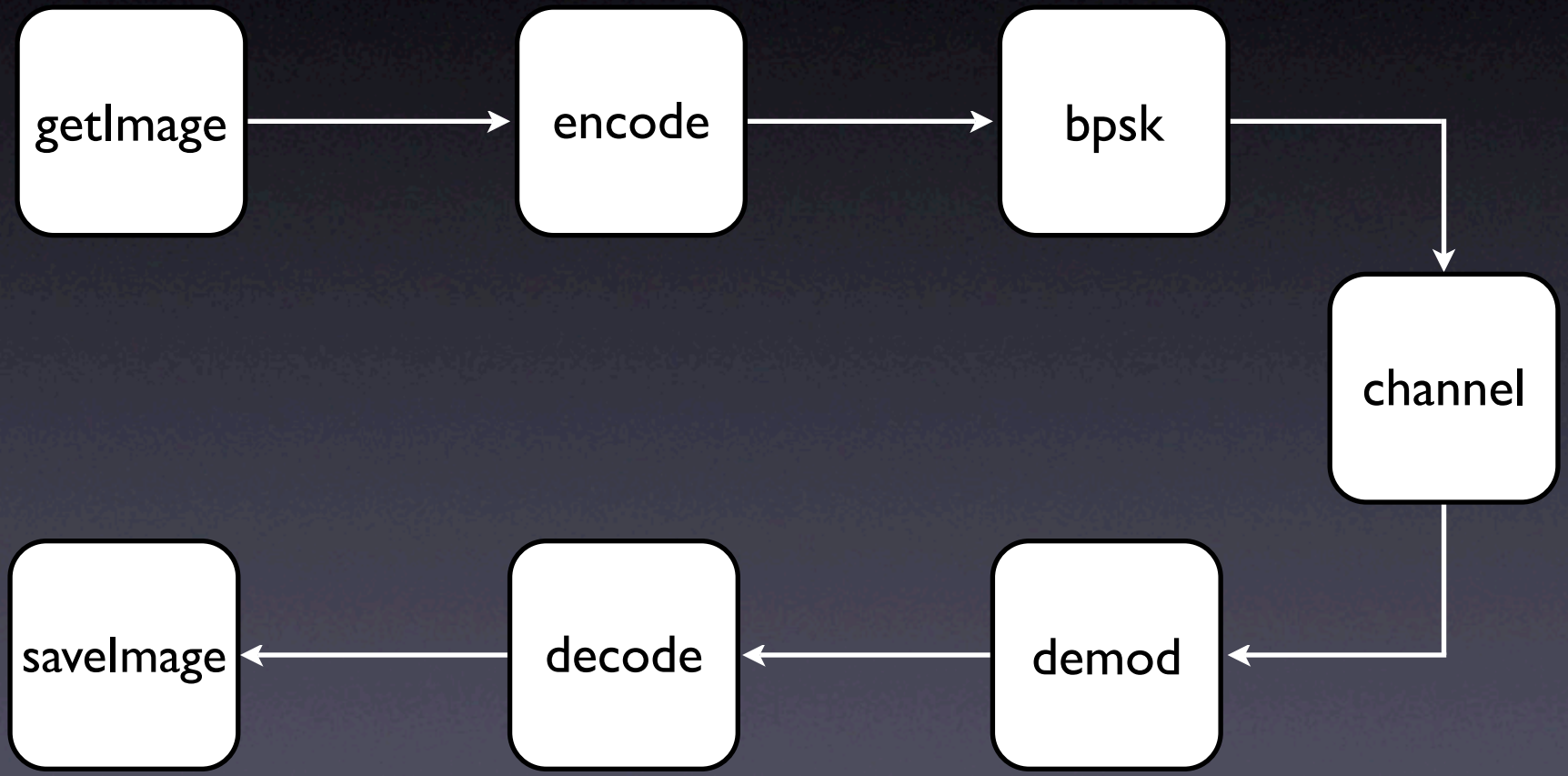
Software Design

- Pipes & Filters Model
- Simulation Scripts

Pipes and Filters



Pipes and Filters



Pipes and Filters

- To run a simulation we would make the following call on a Unix system (modulo program arguments)

```
getImage | encode | bpsk | channel | demod | decode | saveImage
```

Pipes and Filters

- *Advantages*:
  - Easy to develop, test, and debug since the large program is broken up into smaller and simpler ones
  - It is possible to write each program out of order (like we did!) and put the pieces together at the end

Pipes and Filters

- *Disadvantages:*
  - Slightly slower runtime since you are not manipulating memory between components
  - A lot of components to keep track of

#!Scripting

- Had 2 Perl scripts
  - Codebook creation
  - Simulation
- Have many parameters (dimension, rate, q-value, CSNR, orientation,) all of which have multiple possible values.
  - Could have 1000+ codebooks to create!

Results

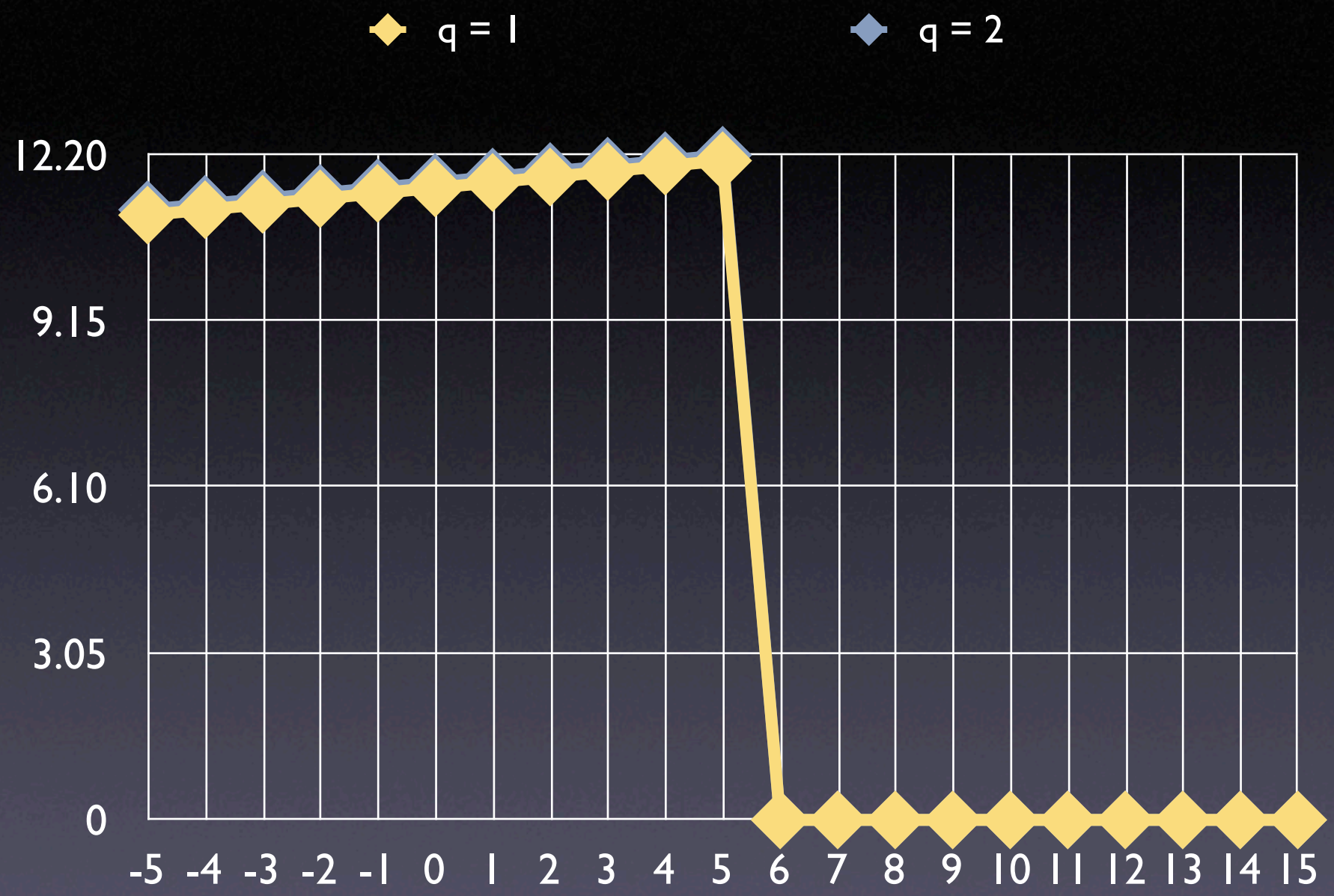
Image Transmission

Image Transmission

- lena original, animation for different q's
- note codebook was trained with this image

Image Transmission

- glasses256.pgm , transmission for various q values
- note codebook was not trained with this image


q = 1
q = 2
12.20
9.15
6.10
3.05
0
-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Advice for the 06's

- We think that the next step in this project would be to ...

Thanks

- Dr. Firouz Behnamfar
- Dr. Fady Alajaji