Predictive Fusion Coding of Spatio-temporally Correlated Sources

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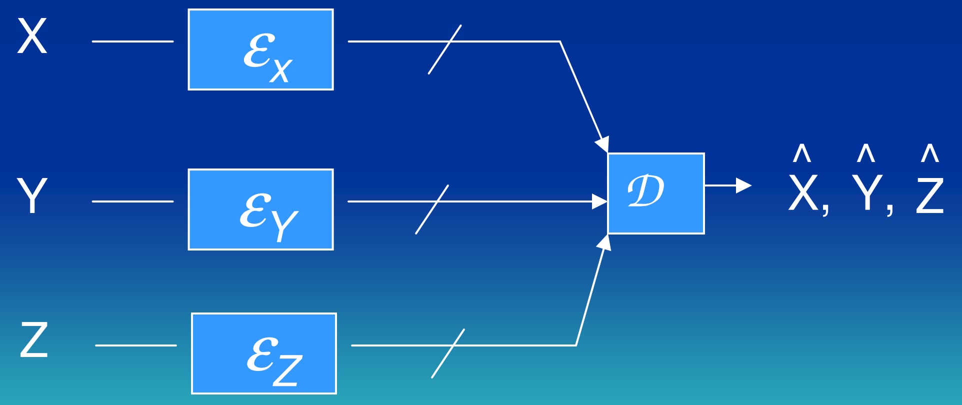
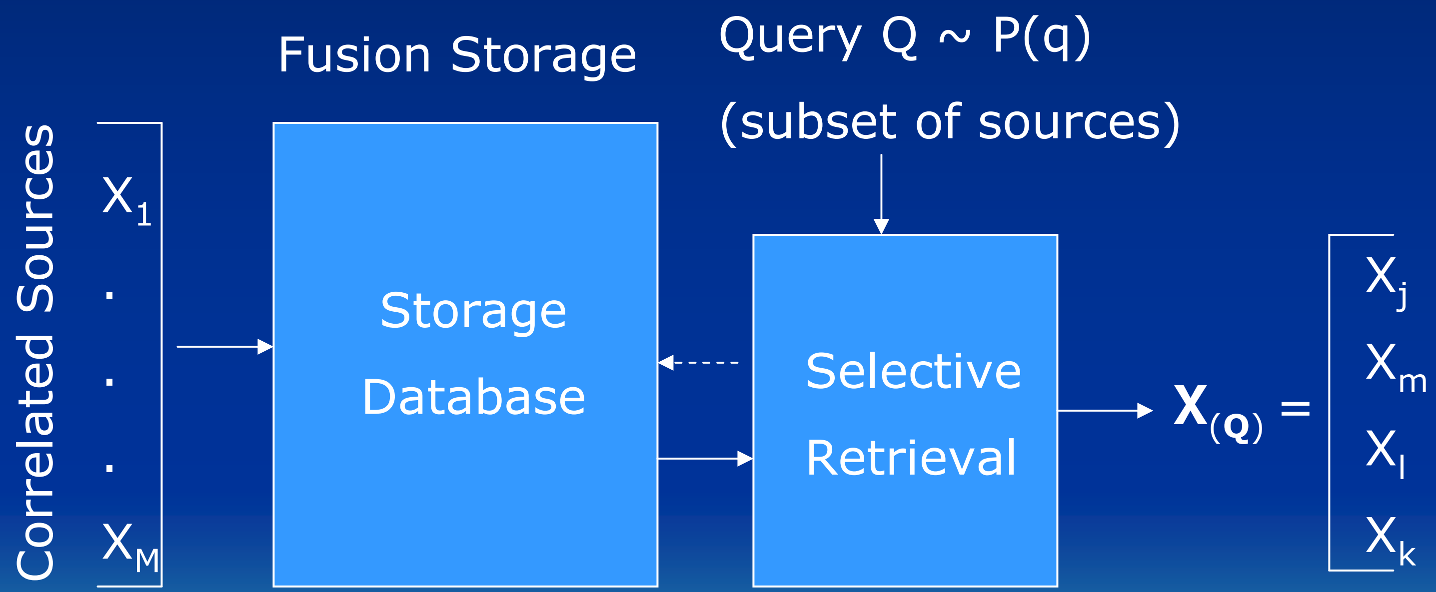
Coding of Correlated Sources …

- Early interest in source coding with side-info (Slepian-Wolf (1973), Wyner-Ziv (1976))
- Other flavors: multi-terminal source coding, distributed source coding
- Applications: distributed compression in sensor networks (DISCUS (1999), Network VQ (2001))



Coding Correlated Sources for Storage

- New setting: *Storage* Media
- *Joint encoding/compression/storage of sources*
- *Selective retrieval of sources*



Storage Rate R_s vs. Retrieval Rate R_r vs. Distortion D

Minimizing Storage Rate

- Compress all sources together
  - minimizes storage

  Lossless Coding $\Rightarrow R_s=H(X_1,\ldots,X_M)$

- Retrieves all stored data for *all queries*
  - high retrieval time!

  $R_r=R_s=H(X_1,\ldots,X_M)$

Minimizing Retrieval Rate

- Compress each subset separately
  - minimizes retrieval rate/time

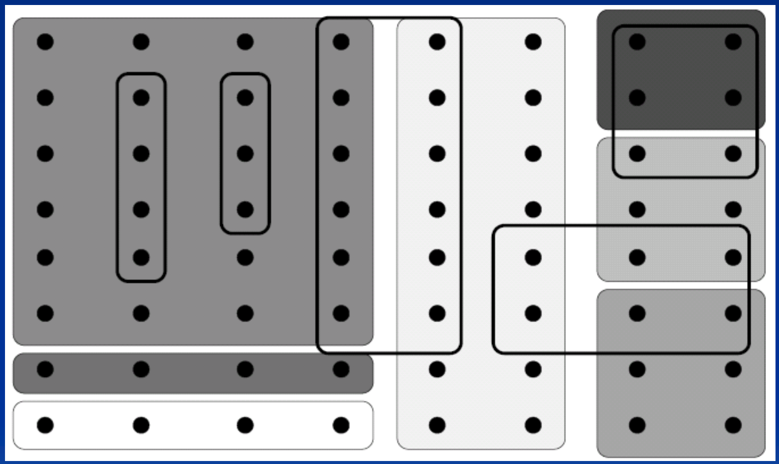
  Lossless Coding $\Rightarrow R_r = \Sigma_q P(q)H(X_{(q)})$

- Reqd. storage grows with size of query set
  - (combinatorially) high storage rate!

  $R_s = \Sigma_q H(X_{(q)}) >> H(X_1,\ldots,X_M)$

Impact/Applications

- Storage, search and retrieval of correlated streams of data e.g. from sensor networks, stocks



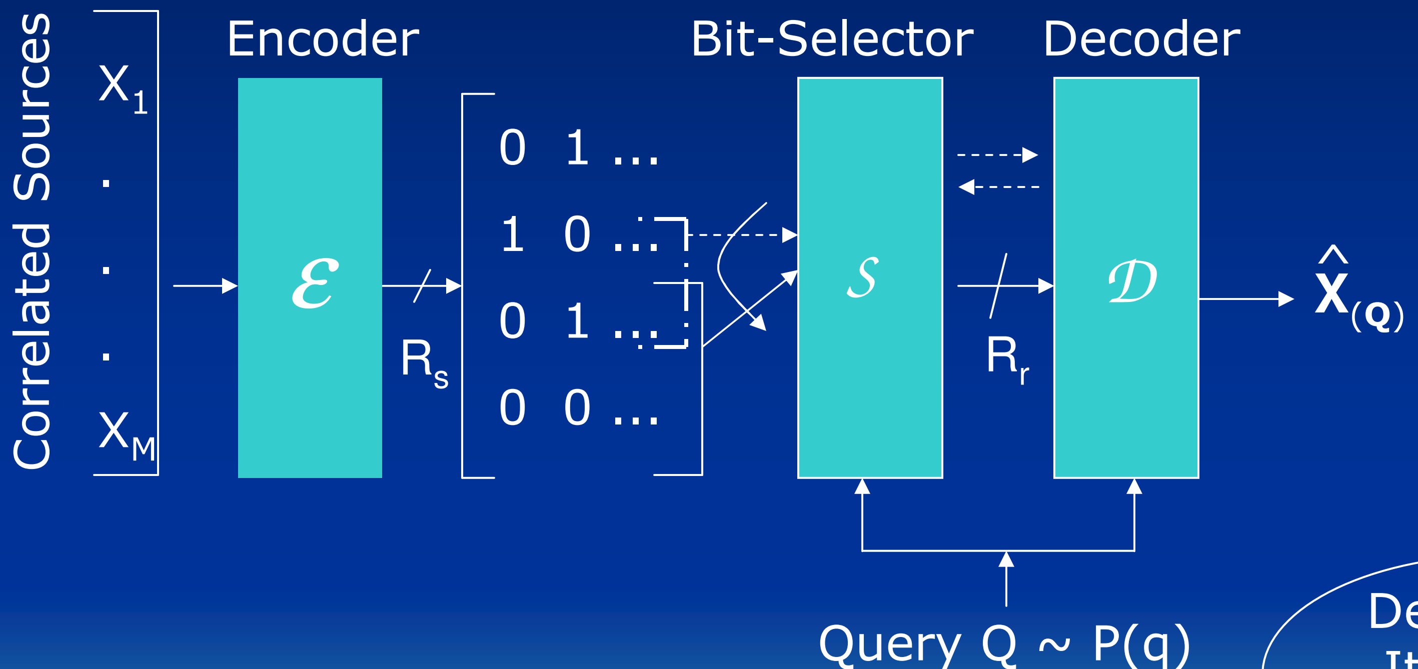
A 2D Sensor Field: boxes are regions of interest

Prior Work on Fusion Storage Coding

- Achievable rates (lossless coding) characterized by Nayak et al (2005)
- "Lossy" fusion coders by Ramaswamy et. al. (2007)
- Storage devices have fixed (limited) storage capacity (R_s)
- Allowed R_s, trade-off between distortion (D) and retrieval rate (R_r) optimized:

$$\min D + \lambda R_r$$

The Fusion Coder (FC)



Query-dependent bit-(subset) selection

Design by Iterative Optimization

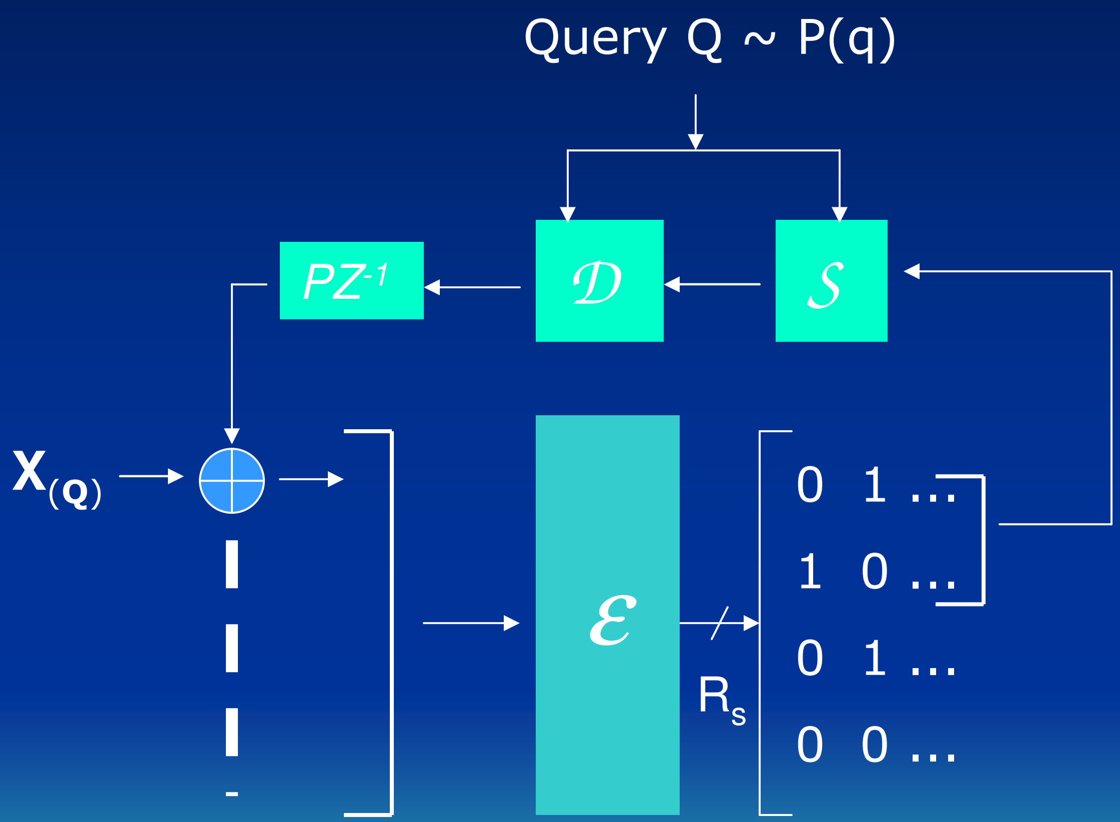
Exploiting time-correlations

- Sensor data exhibit time-correlations

  $\Rightarrow$ fusion code over large blocks (?)
- Coding over large blocks impractical

  - encoding complexities $O(2^{NR_s})$
- Predictive coding – a low complexity alternative

Optimal Predictive Fusion Coding



Complexity of Optimal Predictive Fusion Coding

- $\mathcal{Q}$ - set of queries
- $|\mathcal{Q}|$ prediction loops necessary
- $|\mathcal{Q}|$ prediction error residuals

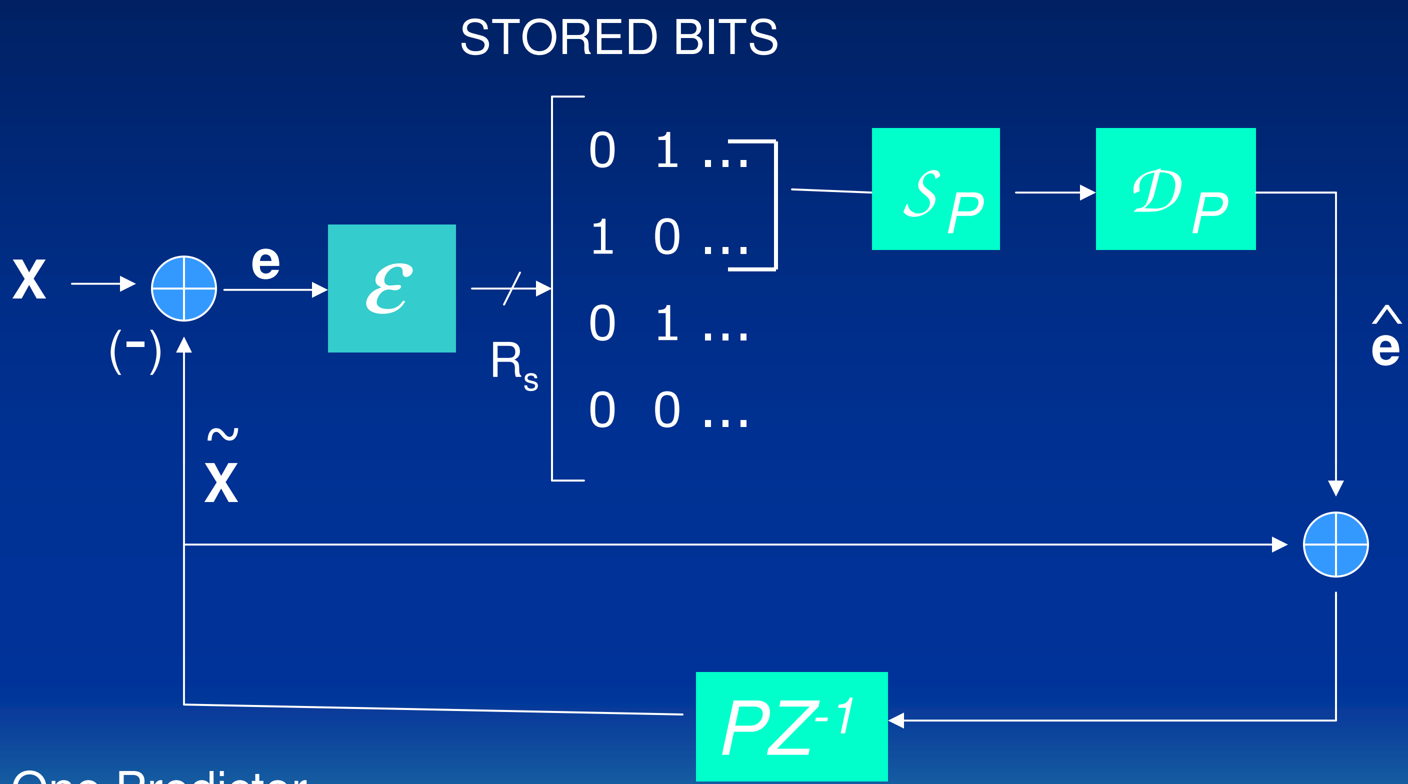
  - grows (combinatorially) with sources
- Dimensionality of input to encoder = $M|\mathcal{Q}|$

  - $M|\mathcal{Q}| >> M \Rightarrow$ high-complexity!!

Constrained Predictive Fusion Coding

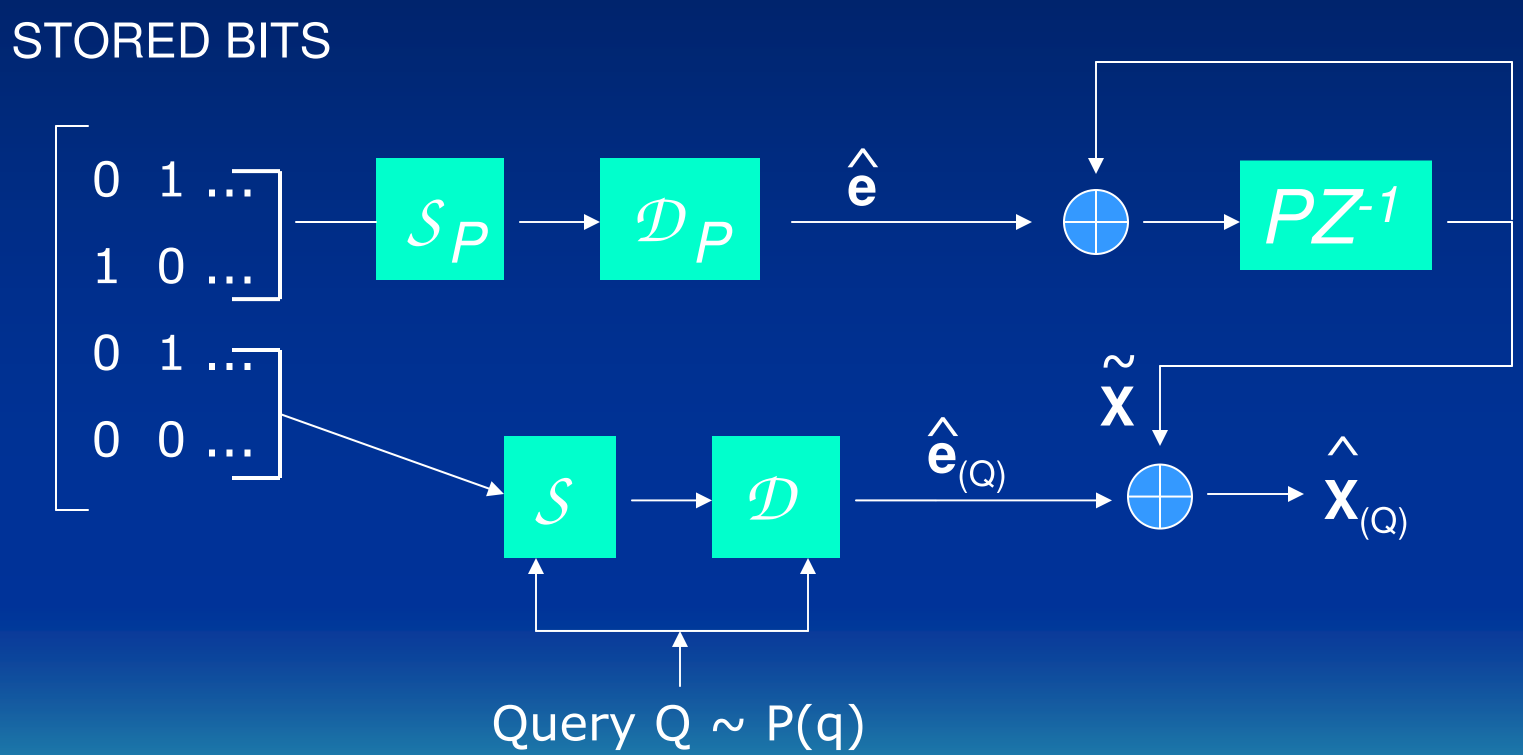
- Constraints imposed for practical designs
- Allow only K prediction loops
- K chosen according to complexity possible
- Queries "share" the K predictors
- Zero "drift" between encoder and decoder
- Prediction bit-selector $\mathcal{S}_P$ vs. Query bit-selector $\mathcal{S}(q)$

Constrained Predictive Fusion Coding: Encoder



Only One Predictor
i.e. K=1

Constrained Predictive Fusion Coding: Decoder



Issues in Predictive Coder Design

- Open loop design
  - generate prediction residuals separately
  - design quantizer for residuals
  - codebooks & predictor mismatched
- Closed loop design
  - close prediction loop; iteratively design encoder & decoder
  - residuals (training set) change unpredictably during design
  - unstable (feedback loop) at low rates

Asymptotic Closed Loop Design

- Always design in open loop
  $\Rightarrow$ stable design
- Gradually change training set in between design iterations
- Asymptotically loop is closed
  $\Rightarrow$ no mismatch of codebooks and predictor
- ACL design necessary for PFC design
  - since $R_s < M$ (low compression rate)

ACL Update Rules

1. Reconstruct source sequence $\hat{X}(n)=\tilde{X}(n)+\hat{e}(n)$
   - for next iteration, new $\tilde{X}(n)=P\hat{X}(n-1)$
2. Create new prediction residuals $e(n)=X(n)-\tilde{X}(n)$
   (in one go, avoiding the prediction loop)
3. Update all encoder and decoder mappings
4. Evaluate cost.
   If converged STOP,
   ELSE go to step 1

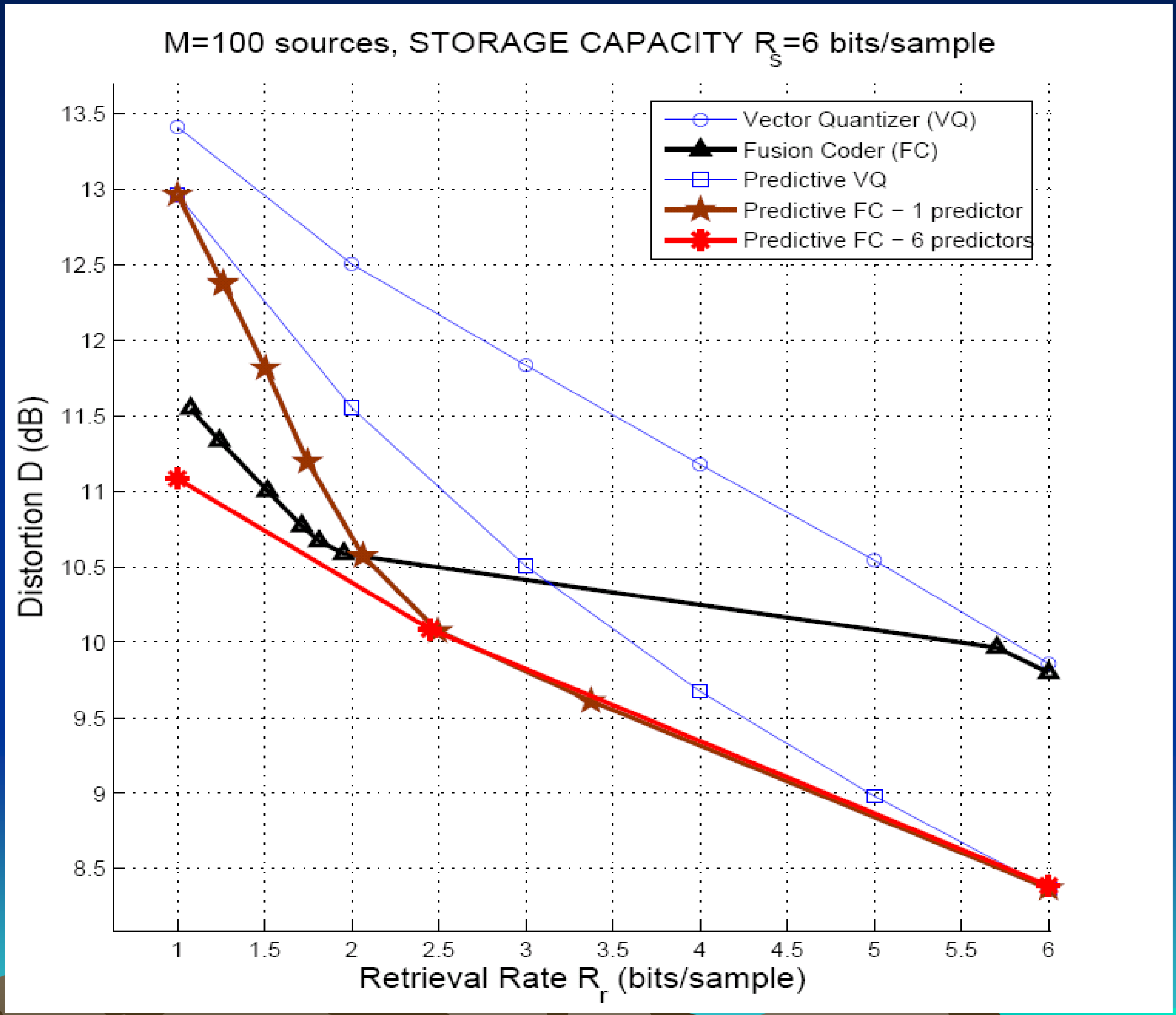
FOR DETAILS, REFER PAPER

Experiments

- M Correlated 1st order Gauss-Markov sources
- $E(W_i W_j)=\rho_{ij}=\rho^{|i-j|}$ ≡ linear sensor array
- $X_m(n)=\beta_m X_m(n-1)+W_m(n), \forall\ 1\leq m \leq M$
- “Neighborhoods” of *n* sources queried

- M=100 sources, ρ=0.95, β_m=0.8 $\forall m$
- n=10, Uniform query distribution, $|\mathcal{Q}|$=91

Results



M=100 sources, STORAGE CAPACITY R_s=6 bits/sample
Vector Quantizer (VQ)
Fusion Coder (FC)
Predictive VQ
Predictive FC − 1 predictor
Predictive FC − 6 predictors
Distortion D (dB)
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Retrieval Rate R_r (bits/sample)

Conclusions

- Fusion coding of correlated sources - an important *storage* problem
- Exploit time-correlations by prediction
- Optimal predictive fusion coder (PFC) has high encoder complexity
- Constrained PFC designed by ACL principle
- Significant gains over memoryless FC and joint compression (VQ)