# Modern Techniques for Flexible, Iterative Source-Channel Decoding

Laurent Schmalen and Peter Vary

FlexCode Public Seminar

June 6, 2007

# Overview

- Soft Decision Source Decoding
- The Turbo Concept of Iterative Decoding
- Generation of Extrinsic Information for the Source Decoder
- Iterative Source-Channel Decoder
- Adaptive, Flexible, Multi-Mode Iterative Source-Channel Decoding scheme

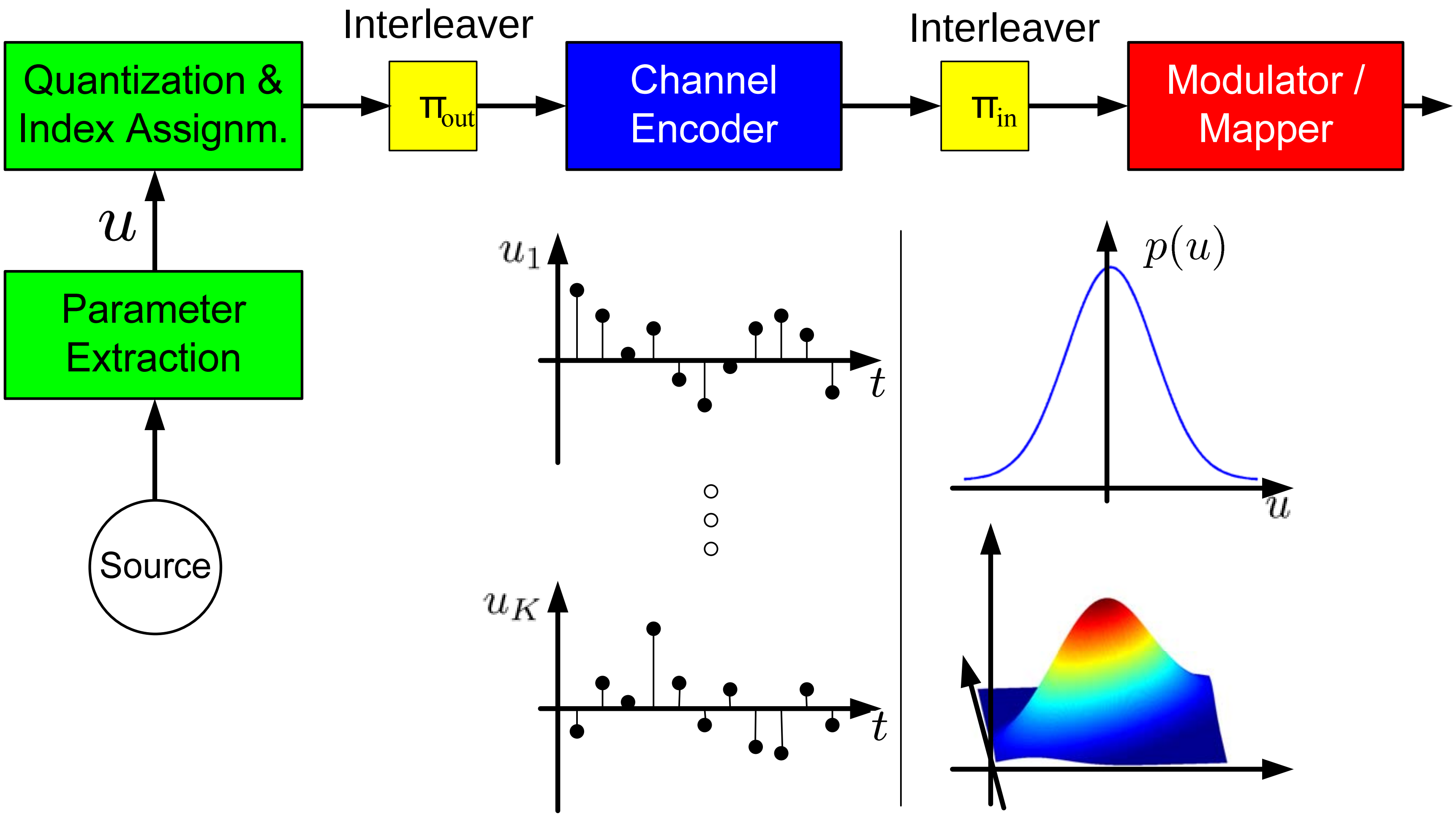
# Introduction

- Channel coding cannot prevent occurrence of residual bit errors in the case of adverse channel conditions leading to a severe degradation of the signal quality
- Annoying effects can be reduced or even eliminated by means of *error concealment*
- Real source coding schemes contain residual redundancy for reasons of delay, complexity and nonstationarity

- Shannon 1948:

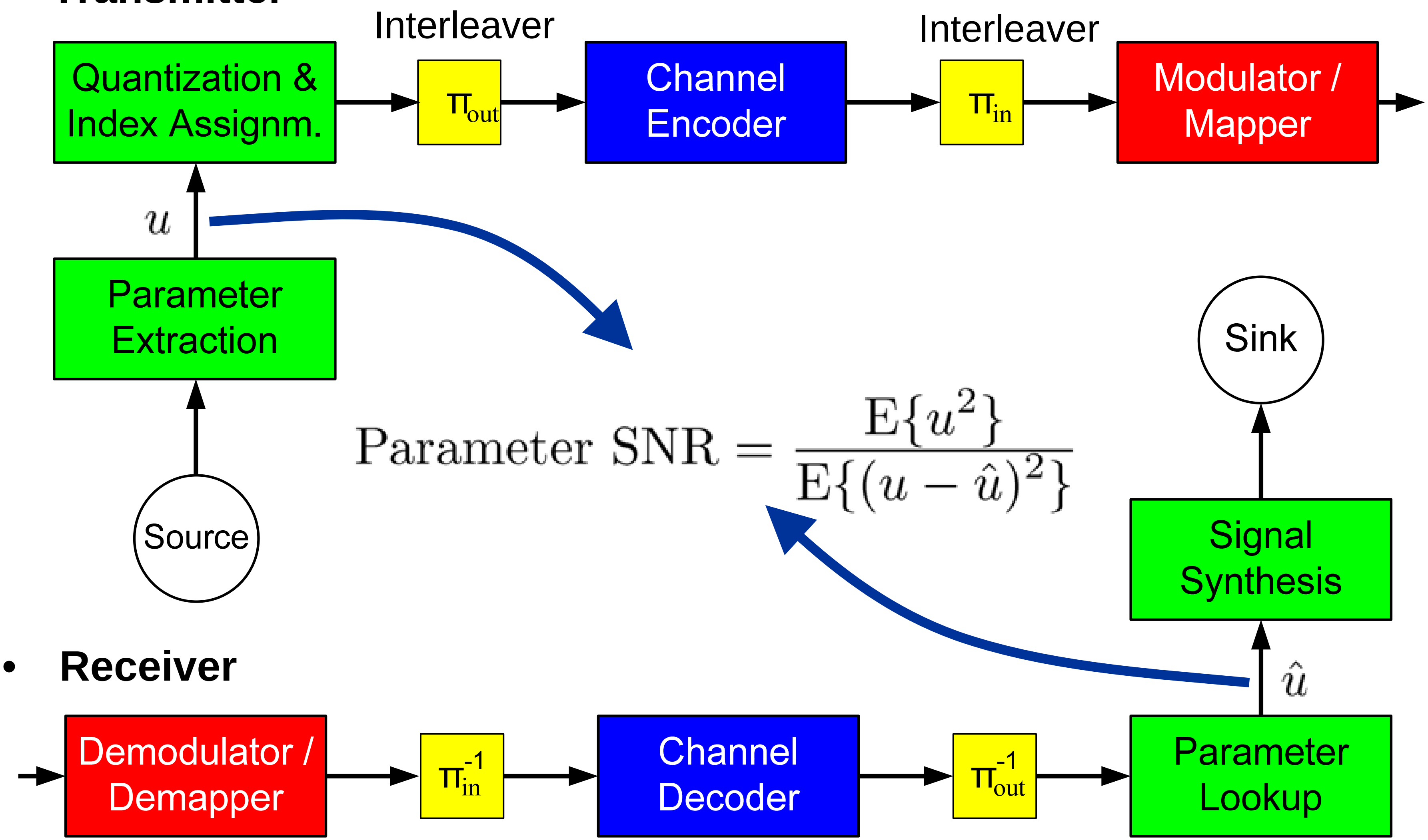
> „However, any redundancy in the source will usually help if it is utilized at the receiving point.
> [...] redundancy will help combat noise."

# Conventional Transmission



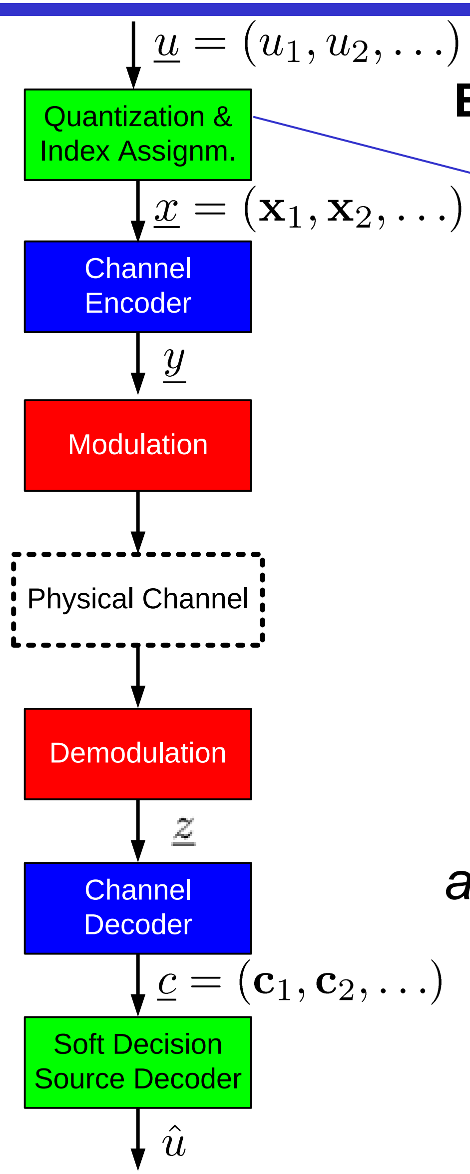
# Conventional Transmission

- **Transmitter**
- **Receiver**

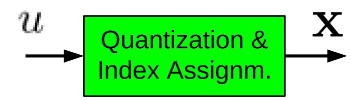



$$\text{Parameter SNR} = \frac{\mathrm{E}\{u^2\}}{\mathrm{E}\{(u-\hat{u})^2\}}$$

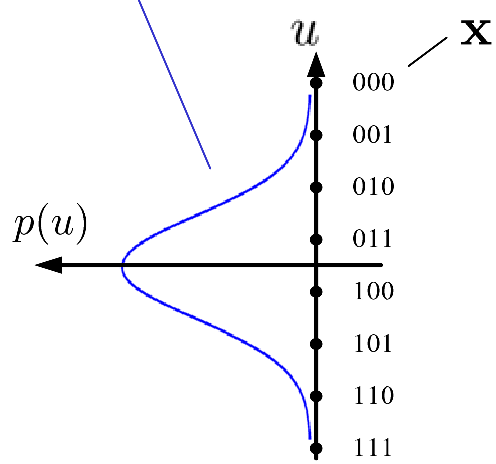
# Soft Decision Source Decoding

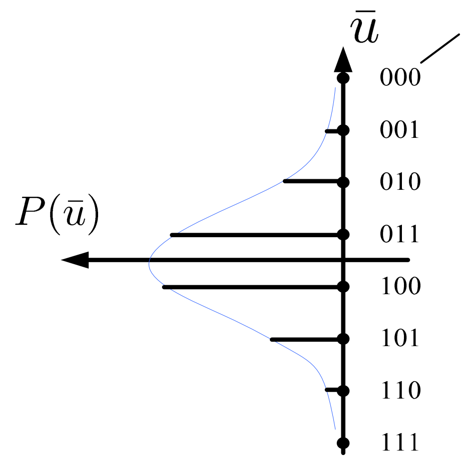



## Exploitation of residual redundancy for quality improvement




1D *a priori* knowledge (parameter distribution)



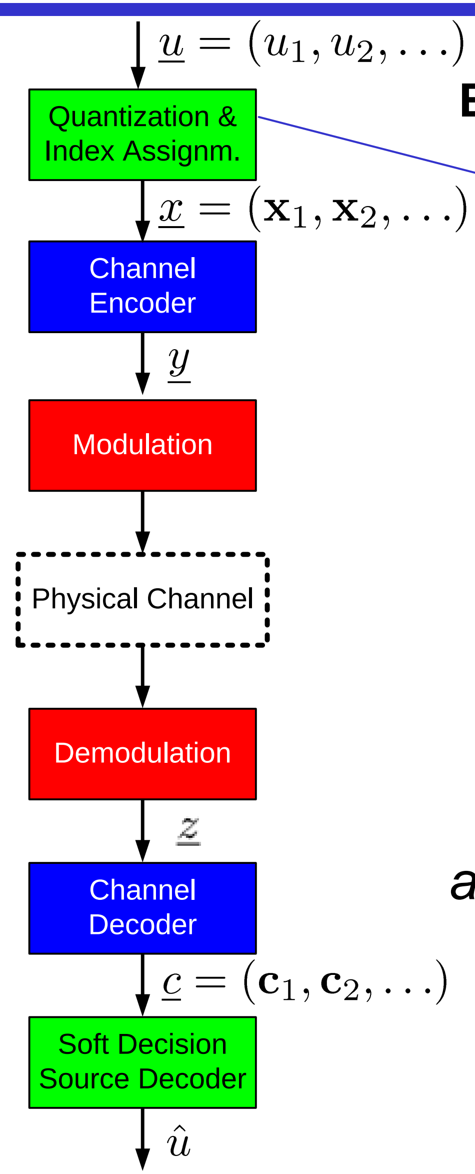

*a posteriori* probabilities: $P(\bar{u}|\underline{c}) = K \cdot P(\mathbf{c}|\mathbf{x}) \cdot P(\bar{u})$

normalization constant

can be calculated using channel statistics

[Fingscheidt01]

# Soft Decision Source Decoding

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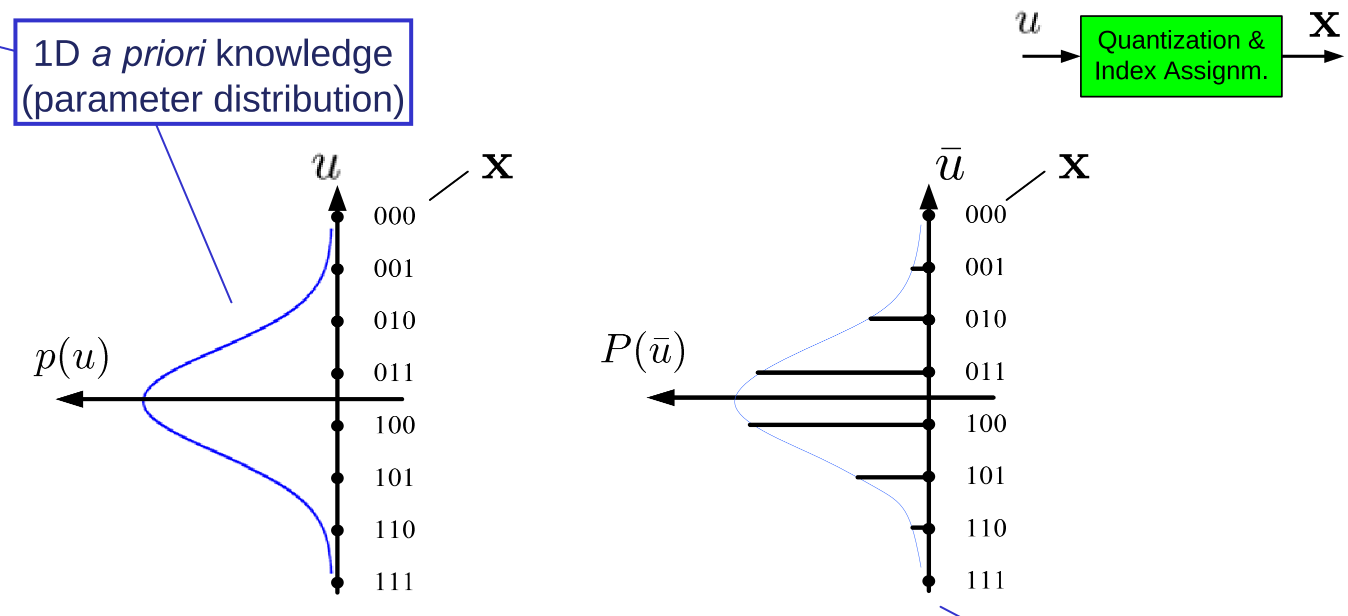


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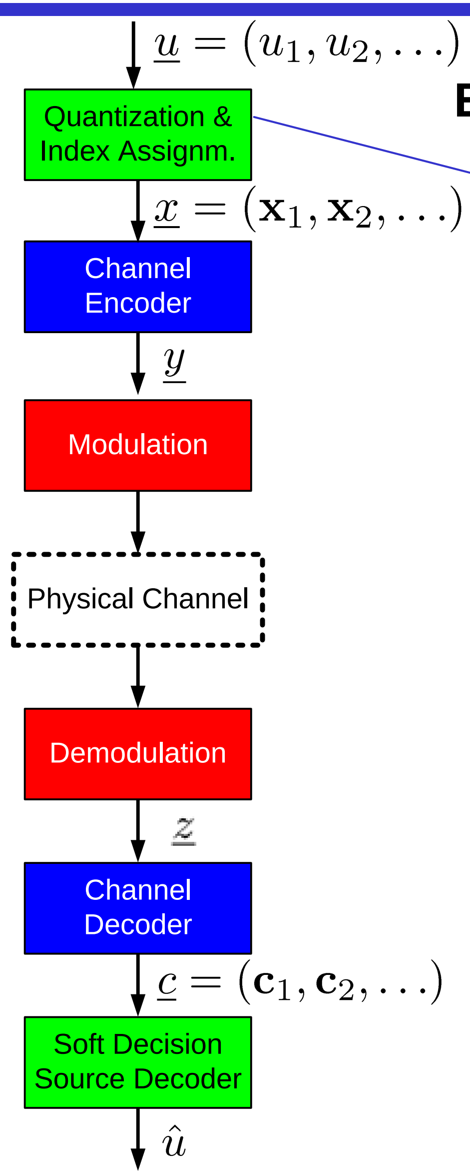
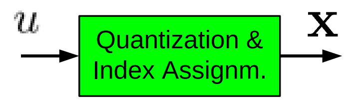
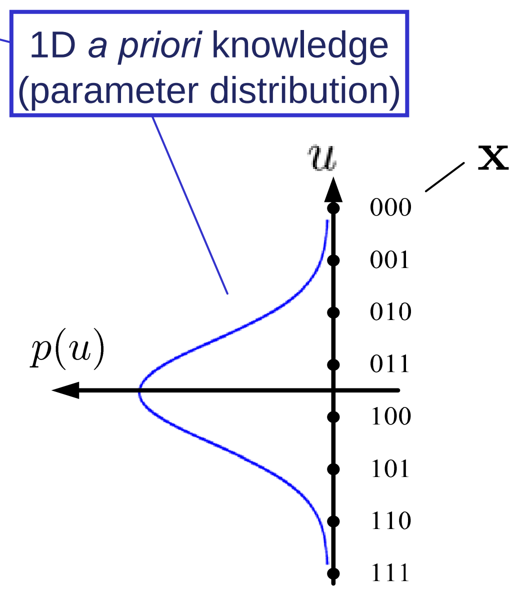
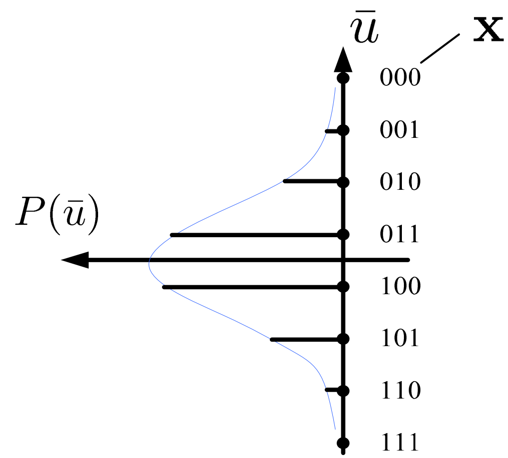



**Exploitation of residual redundancy for quality improvement**



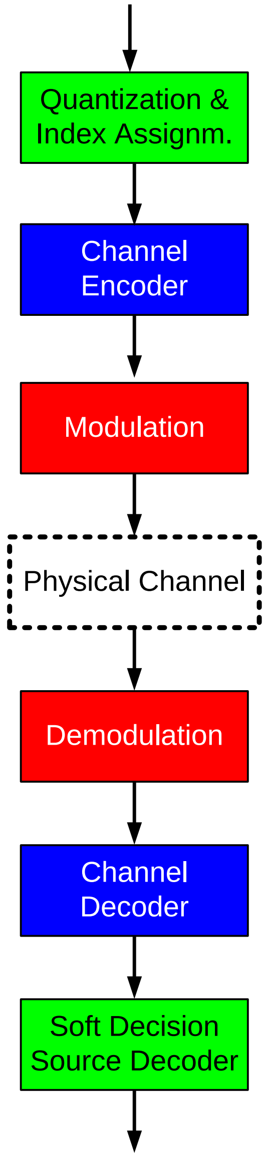




**Parameter estimation instead of table lookup (MMSE estimation using *a posteriori* probabilities)**

$$\hat{u} = \sum_{i=1}^{Q} \bar{u}^{(i)} \cdot P(\bar{u}^{(i)} | \underline{c})$$

[Fingscheidt01]

# Soft Decision Source Decoding

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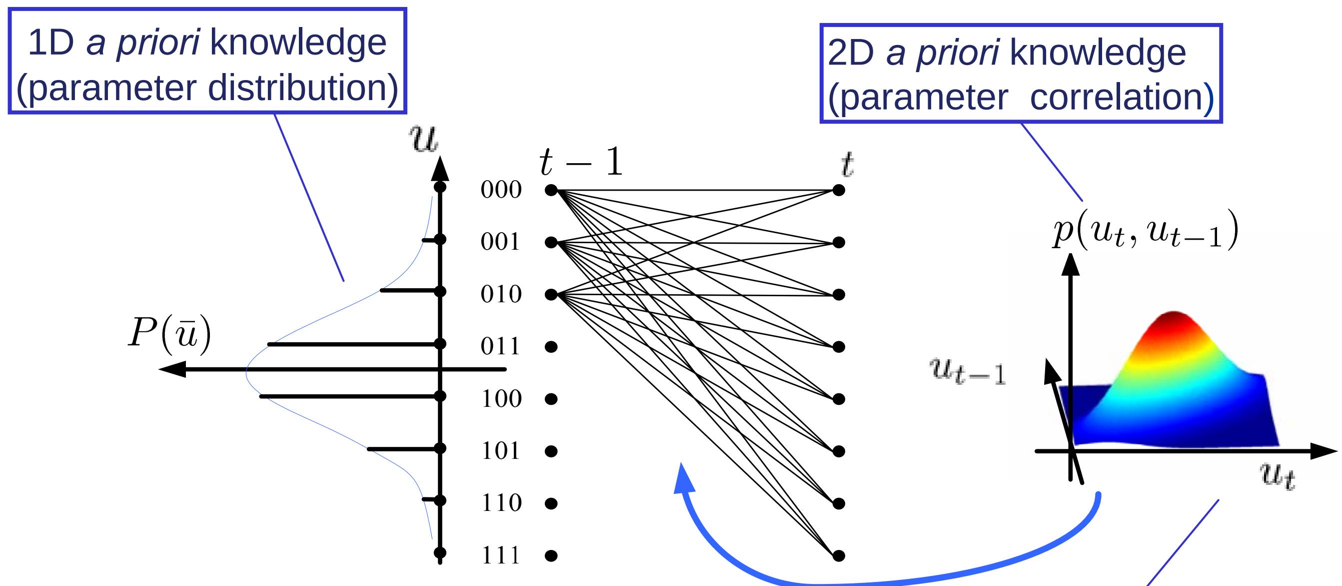


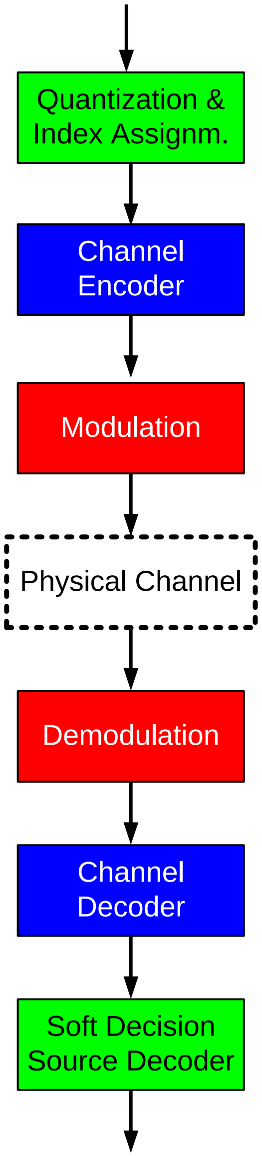

*a posteriori* probabilities can be calculated by the recursion:

$$P(\bar{u}_t|\underline{c}) = K \cdot P(\mathbf{c}_t|\mathbf{x}_t) \cdot \sum_{i=1}^{Q} P(\mathbf{x}_t|\mathbf{x}_{t-1}) \cdot P(\bar{u}_{t-1}|\underline{c})$$

channel statistics

[Fingscheidt01]

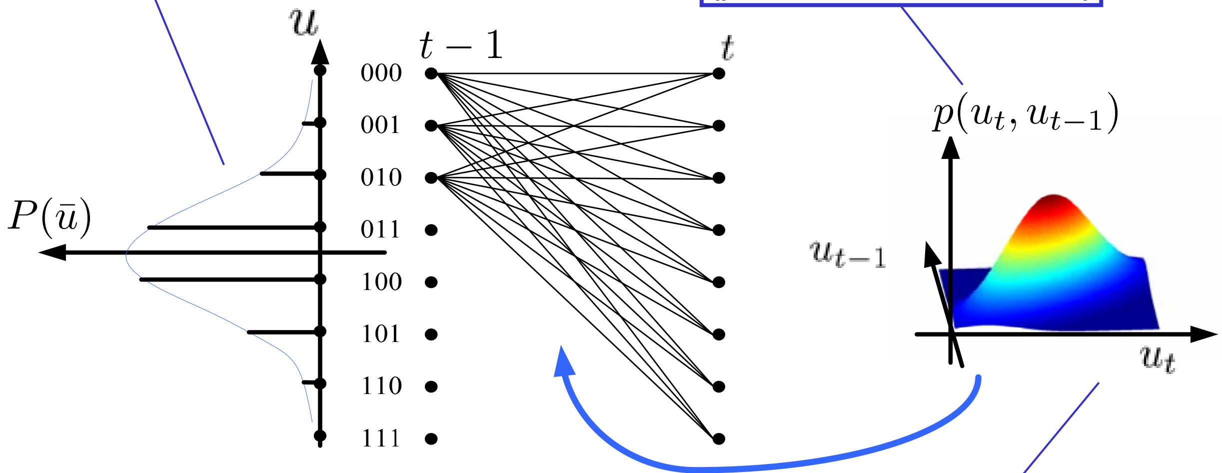
# Soft Decision Source Decoding




## Exploitation of residual redundancy for quality improvement

1D *a priori* knowledge (parameter distribution)

2D *a priori* knowledge (parameter correlation)

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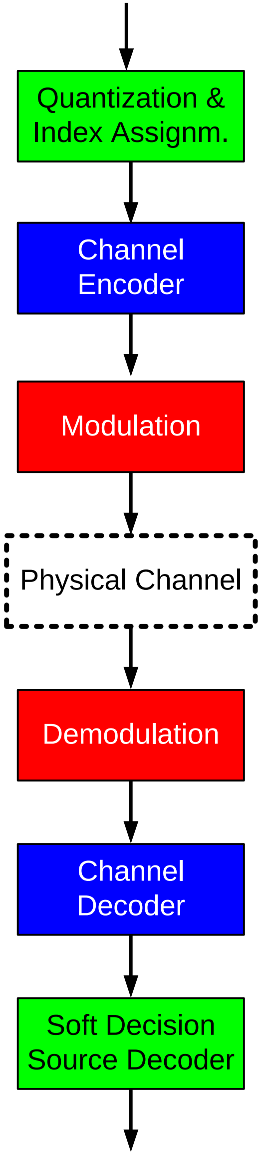
# Soft Decision Source Decoding

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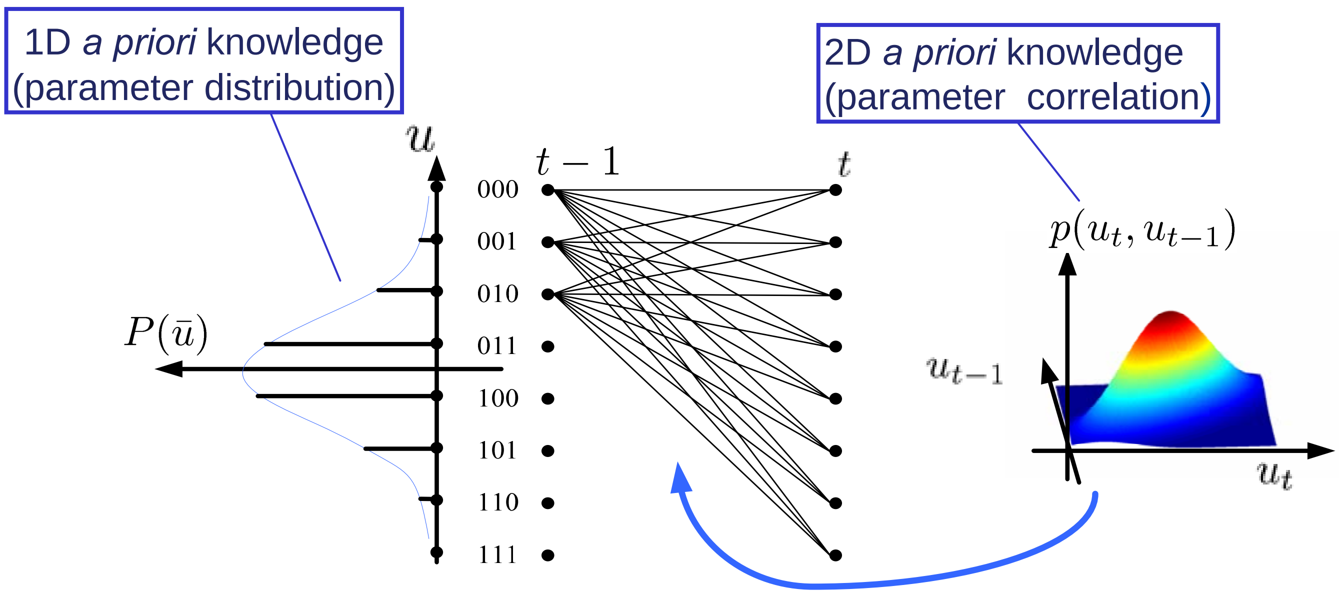



**Parameter estimation instead of table lookup**
**(MMSE estimation using *a posteriori* probabilities)**

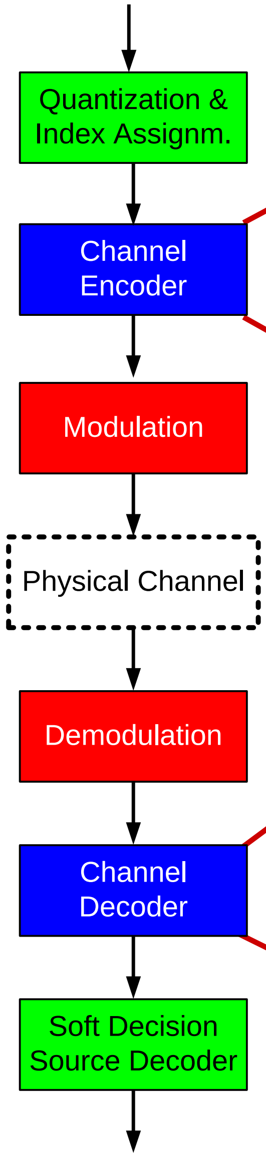
$$\hat{u}_t = \sum_{i=1}^{Q} \bar{u}_t^{(i)} \cdot P(\bar{u}_t^{(i)} | \underline{c})$$

**[Fingscheidt01]**

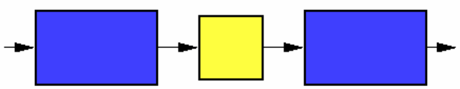
# Iterative Channel Coding

- Timeline of iterative decoding techniques
  - LDPC codes introduced in 1963[Gallager63] but forgotten due to the relatively high complexity at that time
  - Turbo codes invented in 1993[Berrou93]. Allow near-Shannon limit decoding with moderate complexity
  - LDPC codes rediscovered in 1998[MacKay98]. Decoding is also performed iteratively using belief propagation
  - Extension of the iterative decoding to other receiver components, e.g.
    - equalization (Turbo Equalization) [Douillard95]
    - modulation (BICM-ID) [Xi98]
    - multi-user detection (Turbo-MUD) [Alexander98]
    - source decoding (ISCD) [Adrat01], [Goertz01], [Guyader01]

# Turbo Codes, Concept

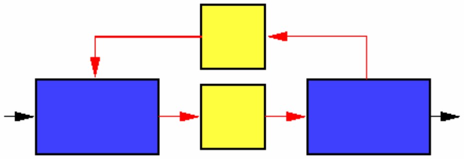



## Concatenated Encoding



serial scheme
[Benedetto98]

## Iterative Turbo Decoding

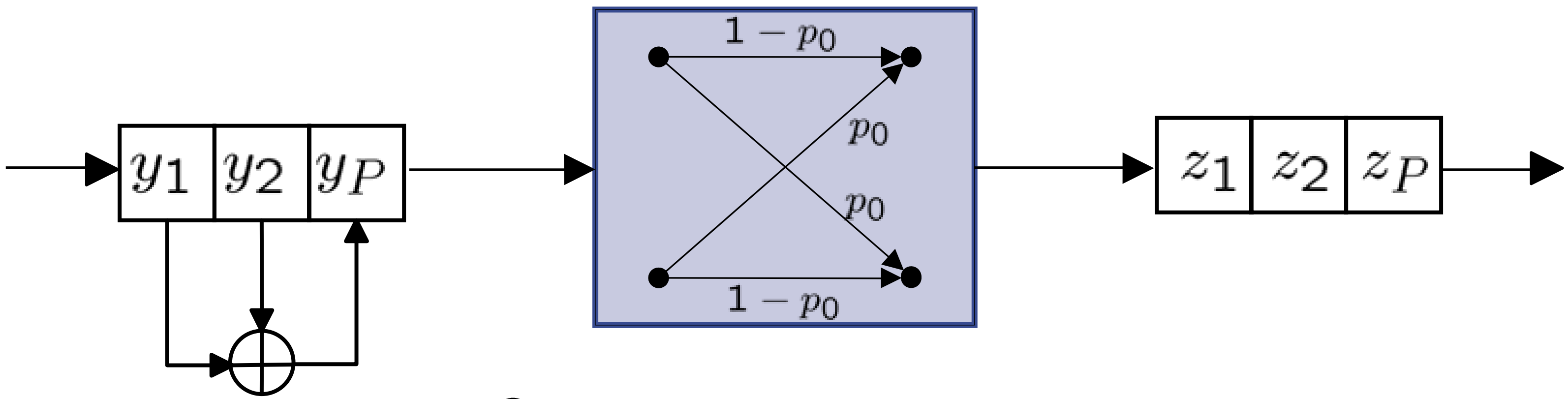


**advantages by iterative feedback!**

# Extrinsic Information

## "Information from neighboring bit positions"

- Example: Parity Check Code




$$y_P = y_1 \oplus y_2$$

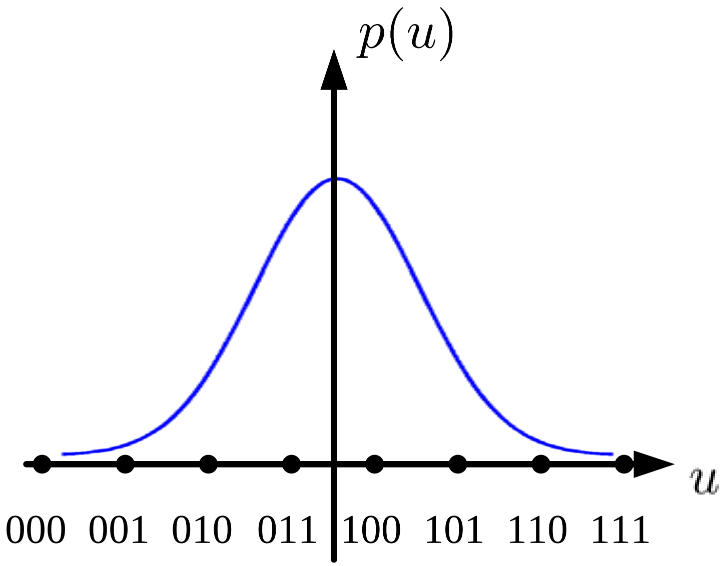
- Extrinsic information:

- transmitter $\Rightarrow y_1 = y_2 \oplus y_P$

- receiver $\Rightarrow \hat{z}_{e1} = z_2 \oplus z_P$

# Extrinsic Information from SDSD

- Generation of extrinsic information by the soft decision source decoder [Adrat03]




Information from channel decoder:

2 rightmost bits are 01

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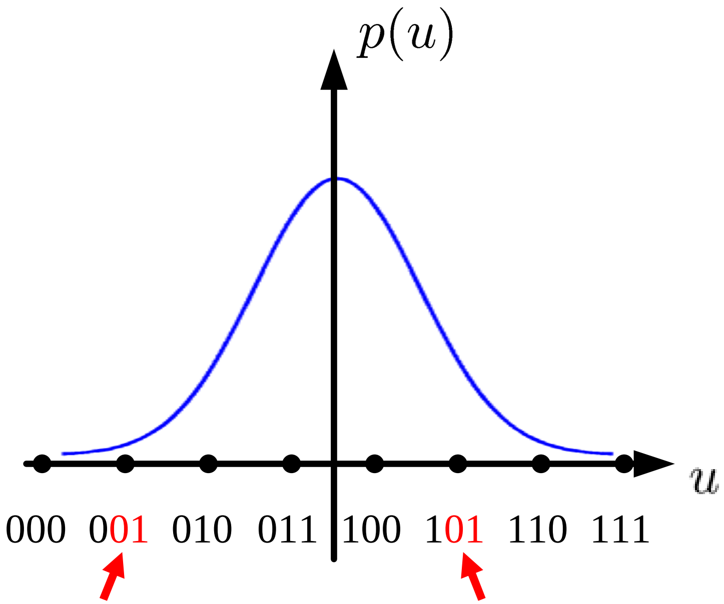


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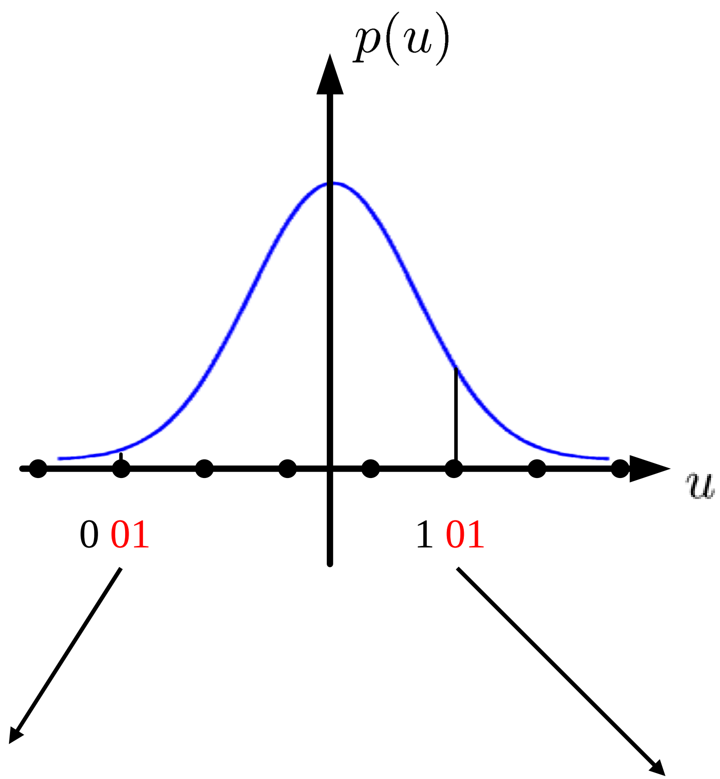


Information from channel decoder:

2 rightmost bits are 01

**This information can be fed back to the channel decoder to improve channel decoding!**

$$P(x_1 = 0 | (x_2, x_3) = (0, 1)) < P(x_1 = 1 | (x_2, x_3) = (0, 1))$$

# Extrinsic Information from SDSD

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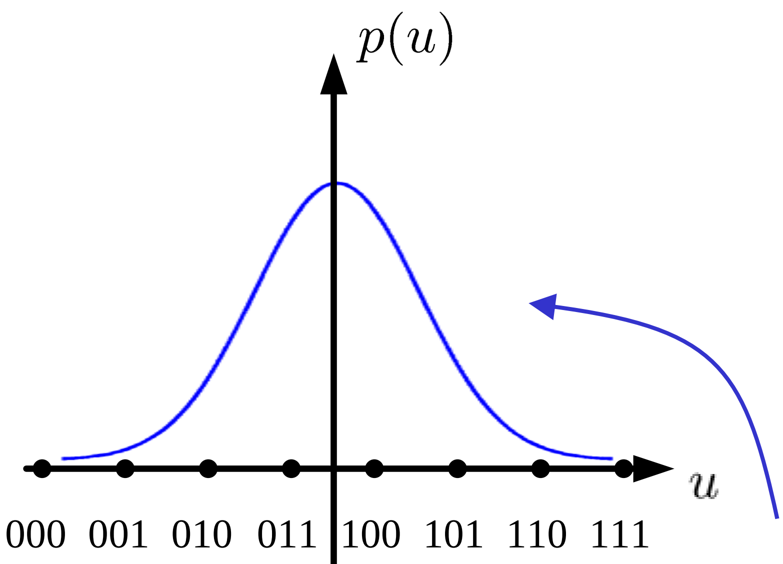
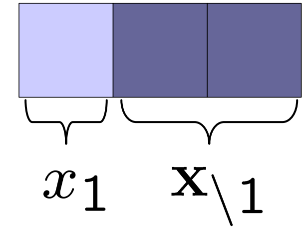



**Usually, the bits are not perfectly known!**

→ marginalization and application of Bayes theorem

Bit pattern $\mathbf{x}$




$$P(x_1 = 1 | \mathbf{c}_{\setminus 1}) = C \cdot \sum_{\mathbf{x}_{\setminus 1}} \overbrace{P(\mathbf{x}_{\setminus 1}, x_1 = 1)}^{\text{a priori knowledge}} \cdot \underbrace{P(\mathbf{c}_{\setminus 1} | \mathbf{x}_{\setminus 1})}_{\text{channel transition probabilities}}$$

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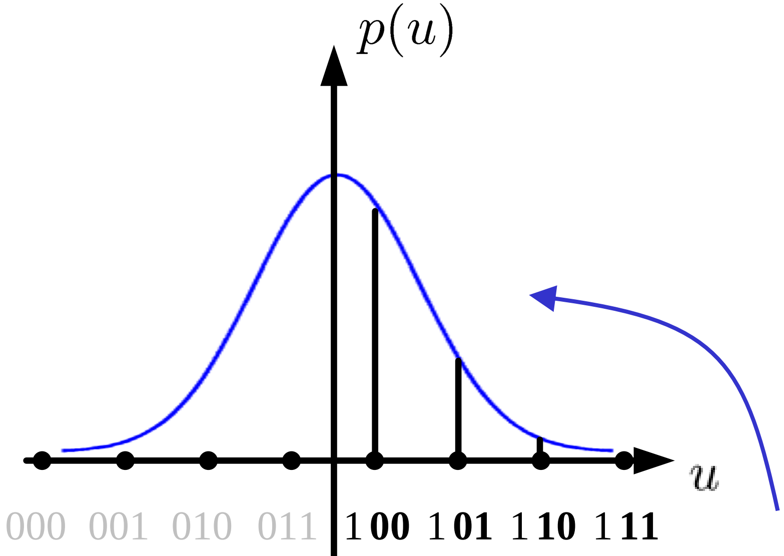


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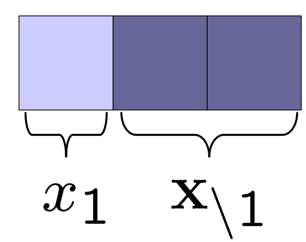


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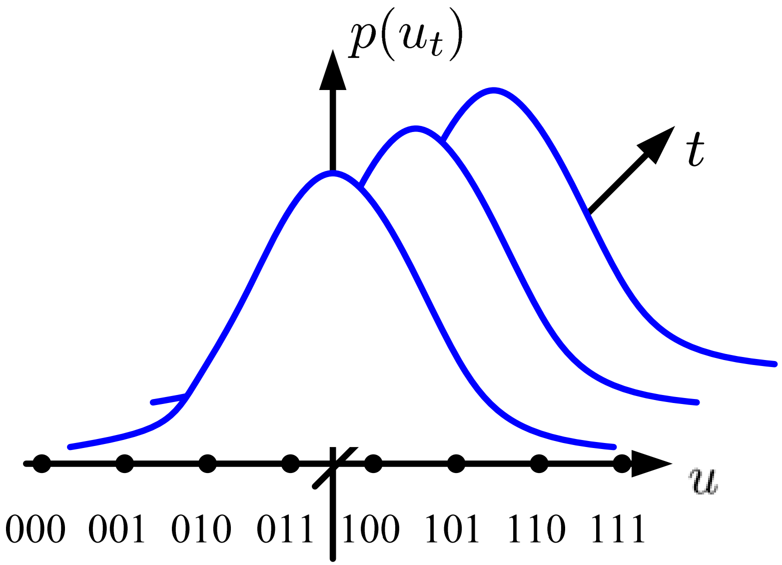
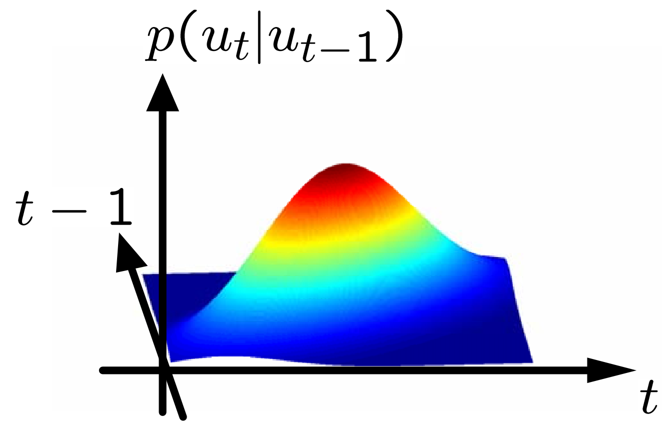
# Extrinsic Information from SDSD

- Correlation of the source is exploited by the SDSD

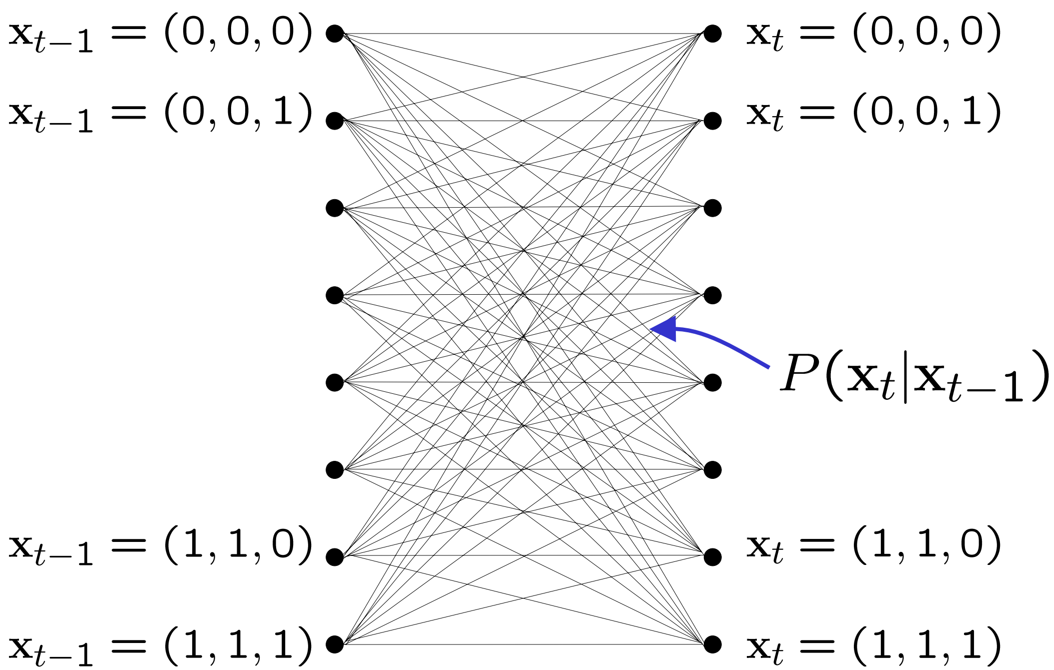



- The quantization of the source modelled as Markov process can be represented using a trellis diagram

# Extrinsic Information from SDSD

- Trellis representation of the source




states correspond to quantizer reproduction levels

state transitions correspond to conditional probabilities

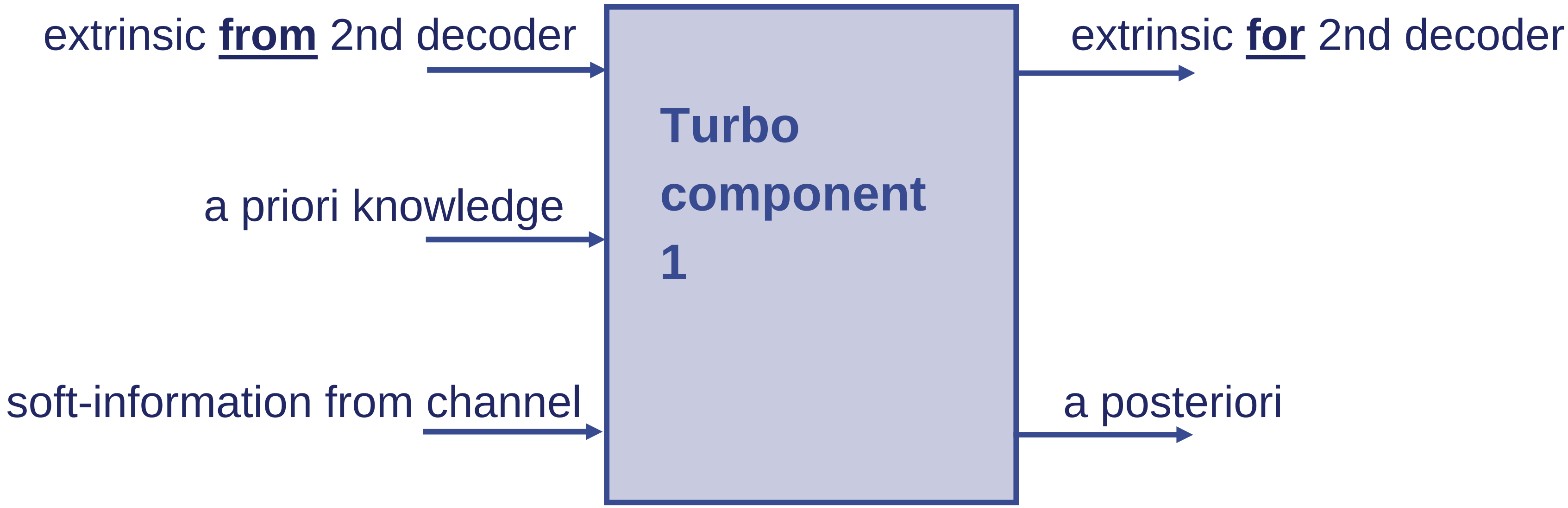
**Decoding using the BCJR (MAP) algorithm**
[Bahl et al. 74], [Heinen 00], [Adrat 05]

- The quantization of the source modelled as Markov process can be represented using a trellis diagram

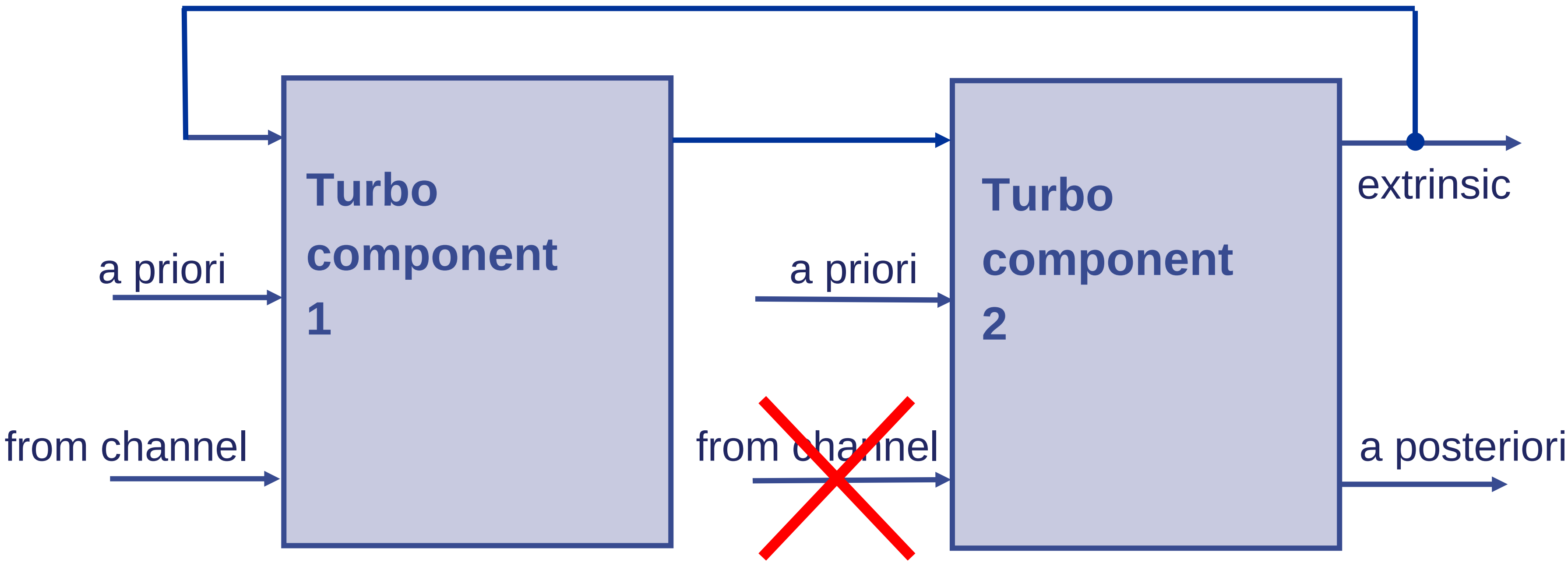
# Extrinsic Information



## Extrinsic Information from a second decoder”



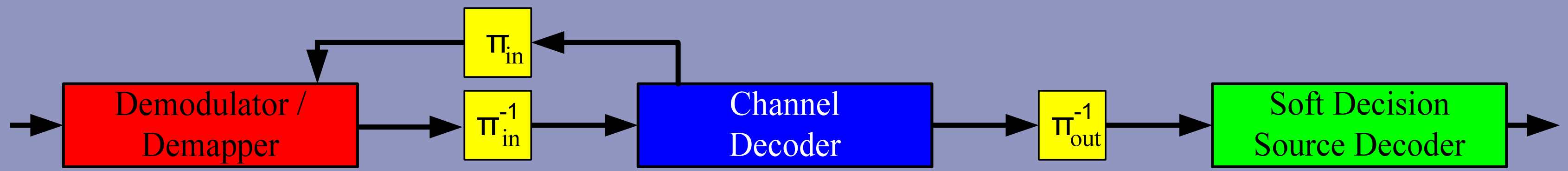
# Iterative Exchange of Extrinsic Information



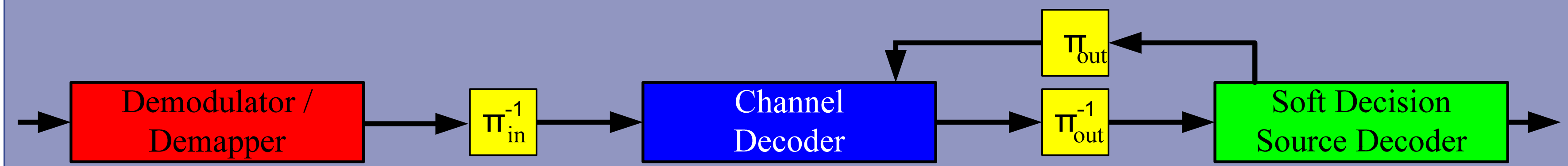

- a posteriori decision after several iterations

# Iterative Decoder Concepts

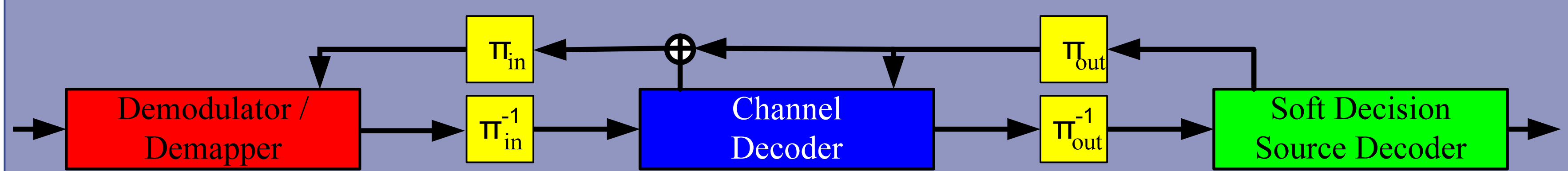
- Bit-Interleaved Coded Modulation & Iterative Decoding [Xi98]




- Iterative Source-Channel Decoding [Adrat01]

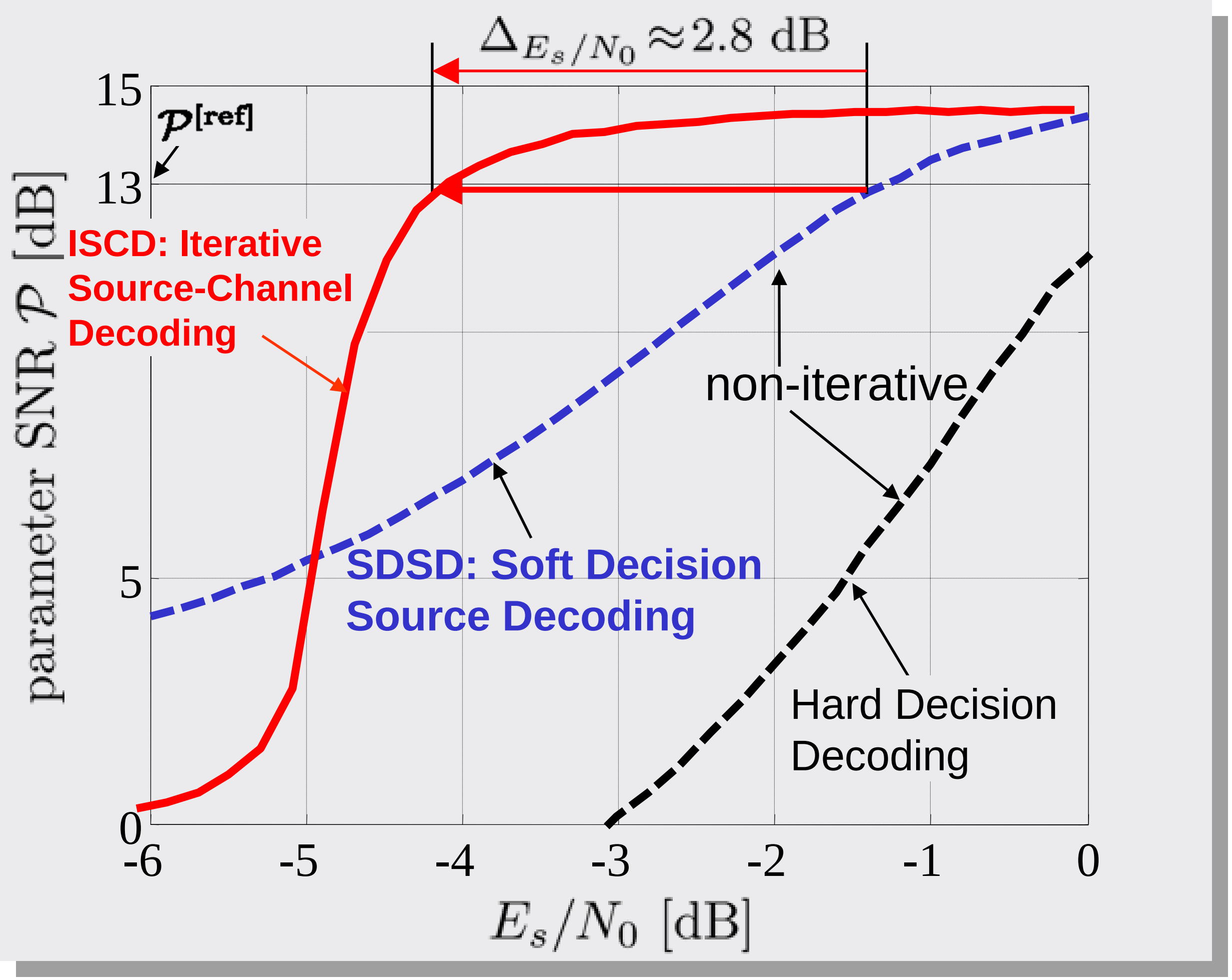



- Turbo DeCodulation [Clevorn05]



# Iterative Source-Channel Decoding

- Design constraint: Parameter SNR e.g. $\mathcal{P}^{[\mathrm{ref}]} > 13$ dB




AWGN / BPSK Modulation

- **250 parameters/frame**
- **auto-correlation $\rho$ = 0.9**
- 3 Bit Lloyd-Max quantizer
- **$r_C$ = 1/2 convolutional code with 8 trellis states**

SDSD:

- ***first order Markov model***

ISCD**:**

- ***recursive non-systematic convolutional code***
- ***EXIT optimized index assignment***
- ***10 iterations***

# Audio Examples



- Audio examples
  - improvement by iterative decoding

| | Speech | Music |
|---|---|---|
| 1 iteration | | |
| 2 iterations | | |
| 3 iterations | | |
| 4 iterations | | |

A-law PCM with 8-bit quantization

AWGN / BPSK Modulation

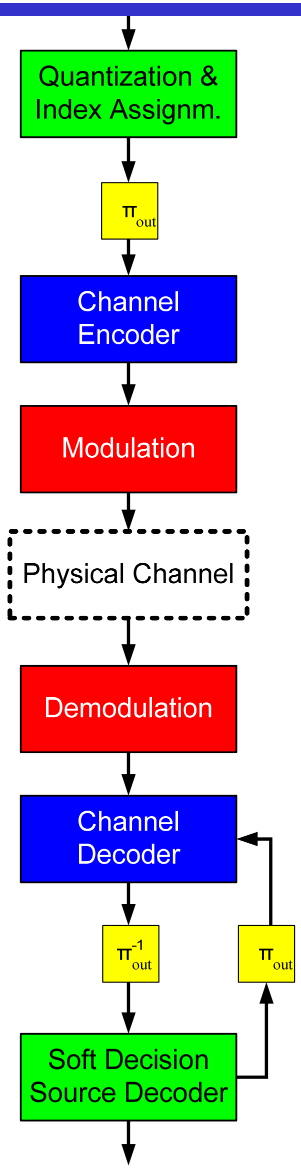
- **44.1 kHz sampling rate**
- **300 samples/frame**
- **$r_C$ = 1 convolutional code with 8 trellis states**
- **redundant $r_{IA}$ = ½ block coded index assignment**
- **$E_s/N_0$ = 1 dB (BER = 5.5 %)**

SDSD:

- **exploiting unequal parameter distribution only (zeroth order apriori knowledge)**

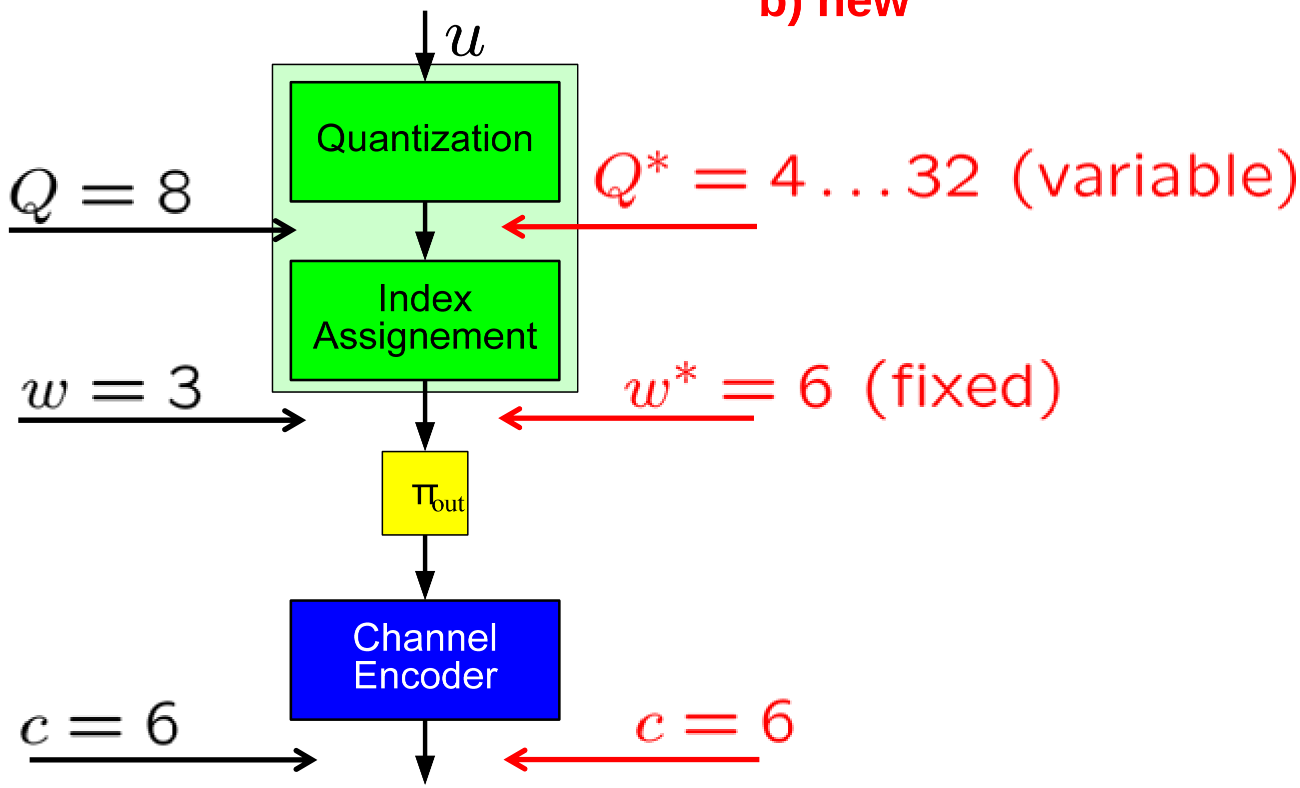
**→ further improvement by exploiting correlation**

# Redundant Index Assignments




- Highly Redundant Index Assignments **[Adrat05]**

**b) new**

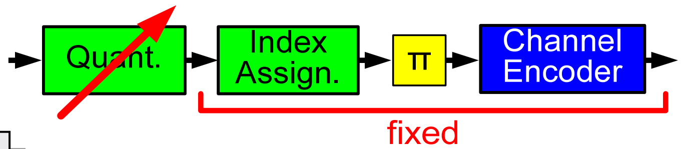


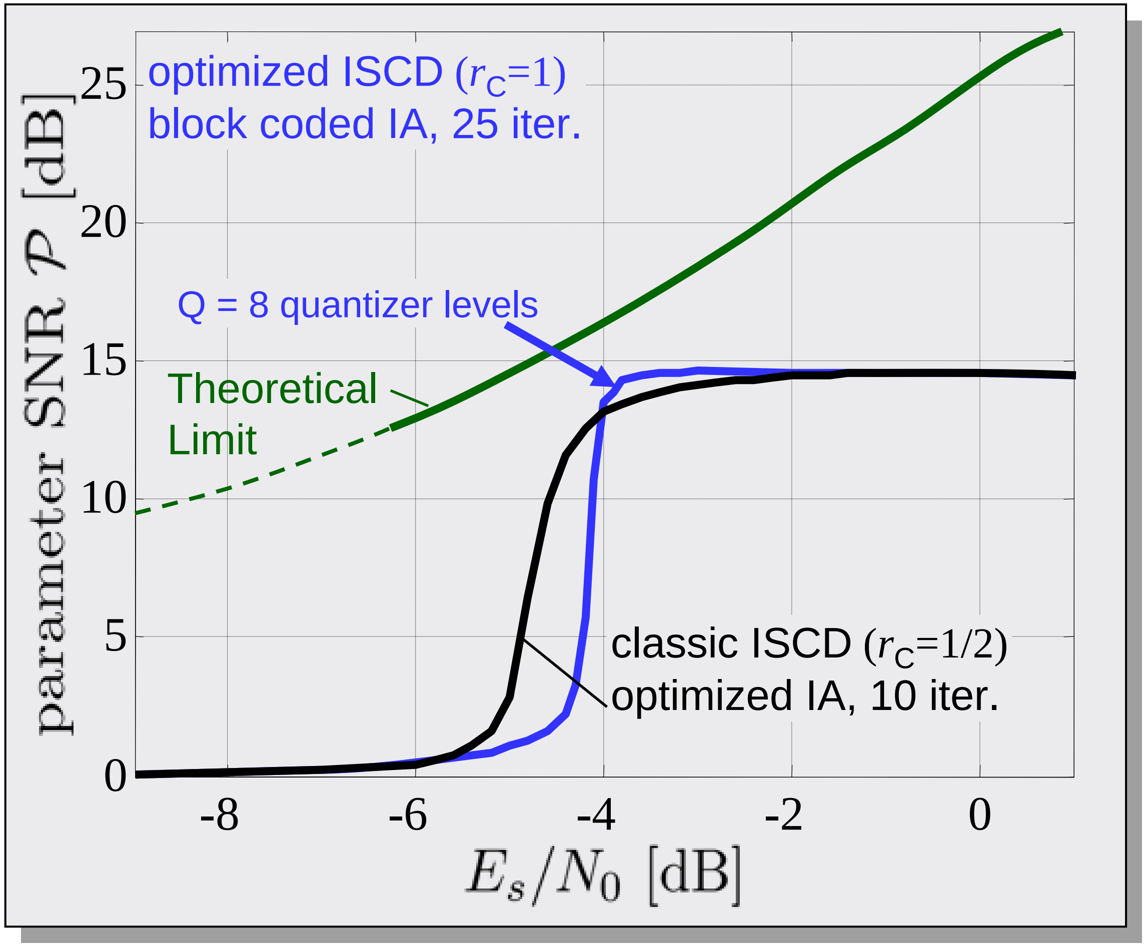

$r_C = w/c = 1/2$ $\quad\quad$ $r_C = w^*/c = 1$

# Iterative Source-Channel Decoding



- **Extension towards a multi-mode system by variable source encoding (Q quantizer levels)**
- **Fixed channel coding with rate *r* = 1**




AWGN channel

- BPSK Modulation
- 250 parameters/frame
- auto-correlation $\rho$ = 0.9
- Lloyd-Max quantizer with Q levels
- 6 bits per parameter
- convolutional code with 8 trellis states
- redundant index assignment

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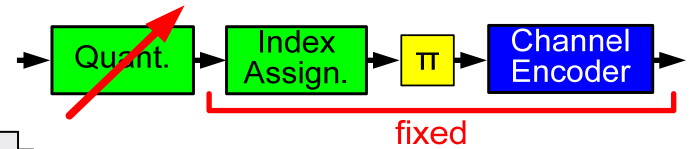


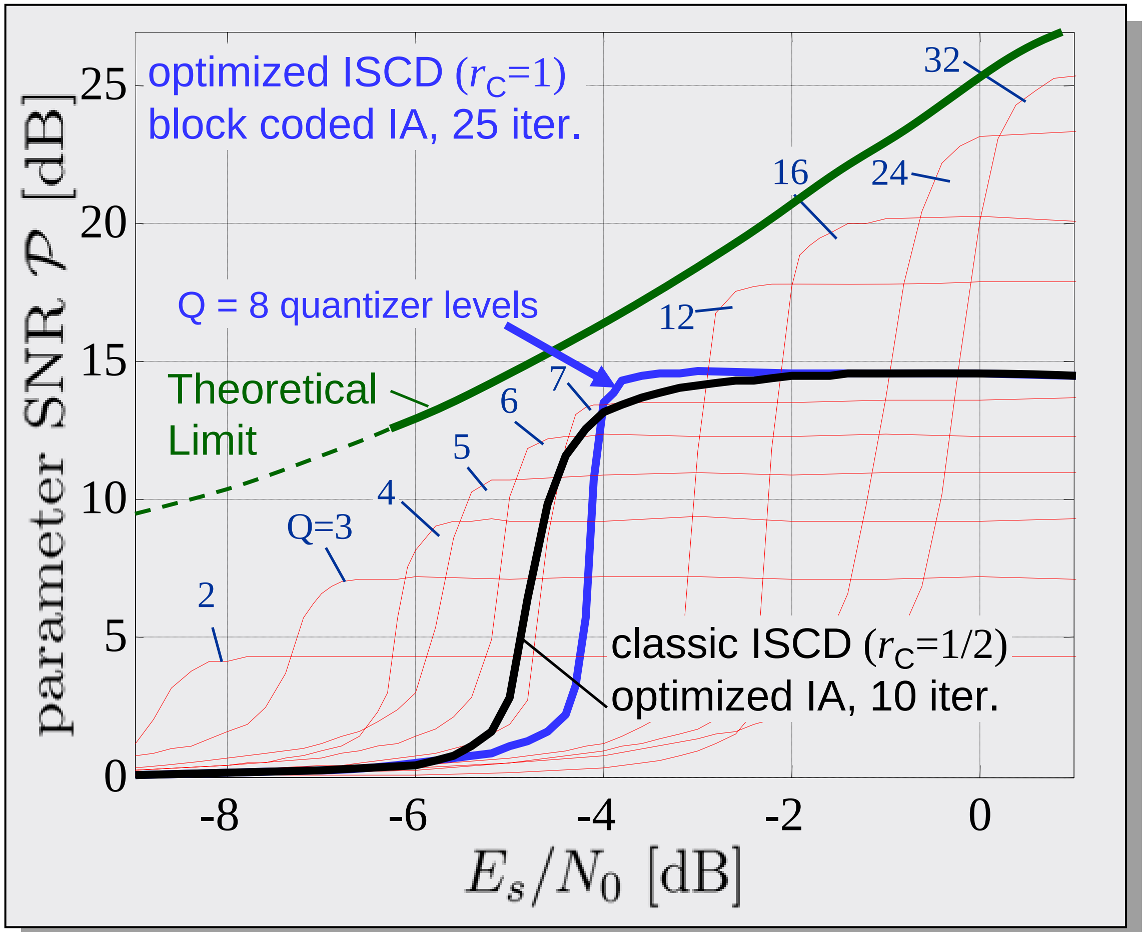


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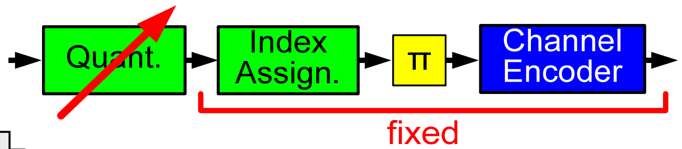


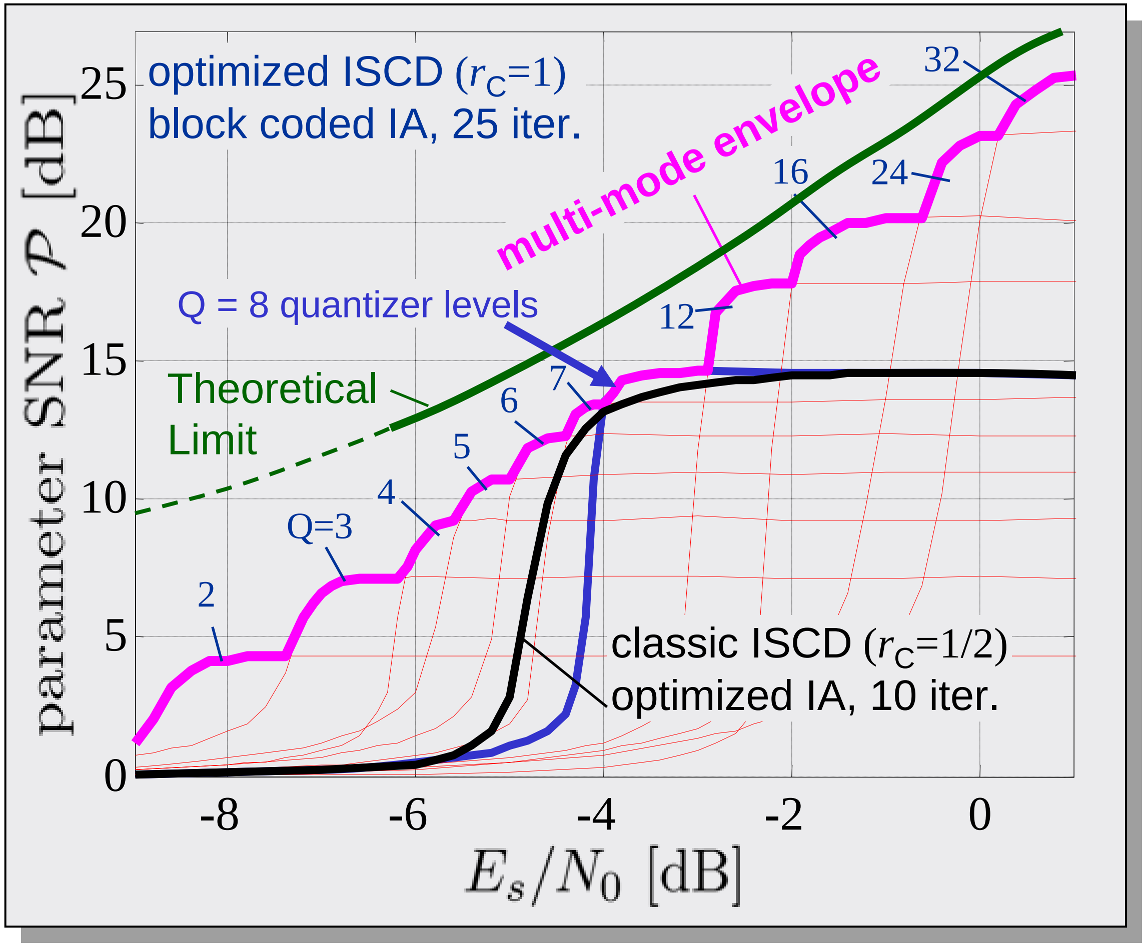


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# Conclusions

- Exploitation of residual source redundancy for soft decision source decoding
- Determination of extrinsic information by using residual source redundancy
- Iterative decoding concept extended to the source decoding step
  - Near capacity decoding of quantized, correlated sources
  - Adaptivity/Flexibility by using a multi-mode transmission scheme

# Modern Techniques for Flexible, Iterative Source-Channel Decoding

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