

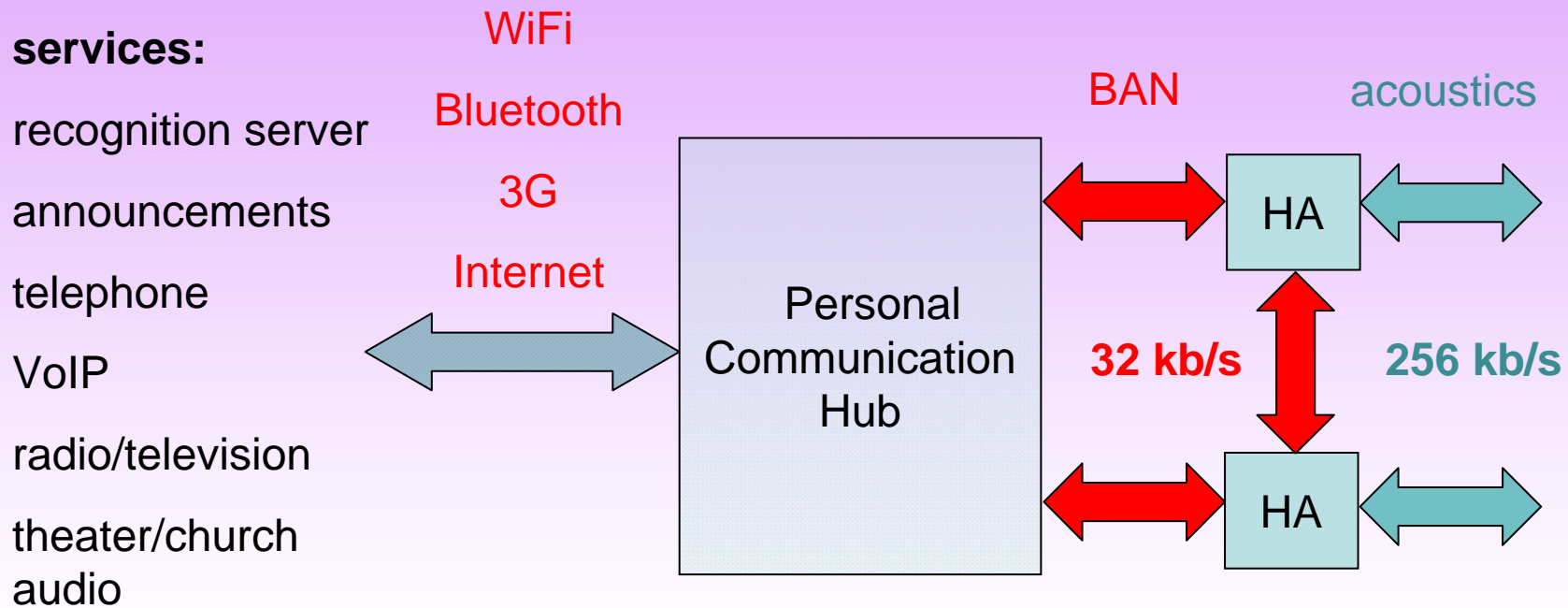
Optimal Codec for Wireless Communication Links

W. Bastiaan Kleijn and Minyue Li
School of Electrical Engineering
KTH - Royal Institute of Technology
Stockholm, Sweden

Workshop Hearing Screening and Technology, Brussels 28 January 2009



HEARCOM Context



Objectives

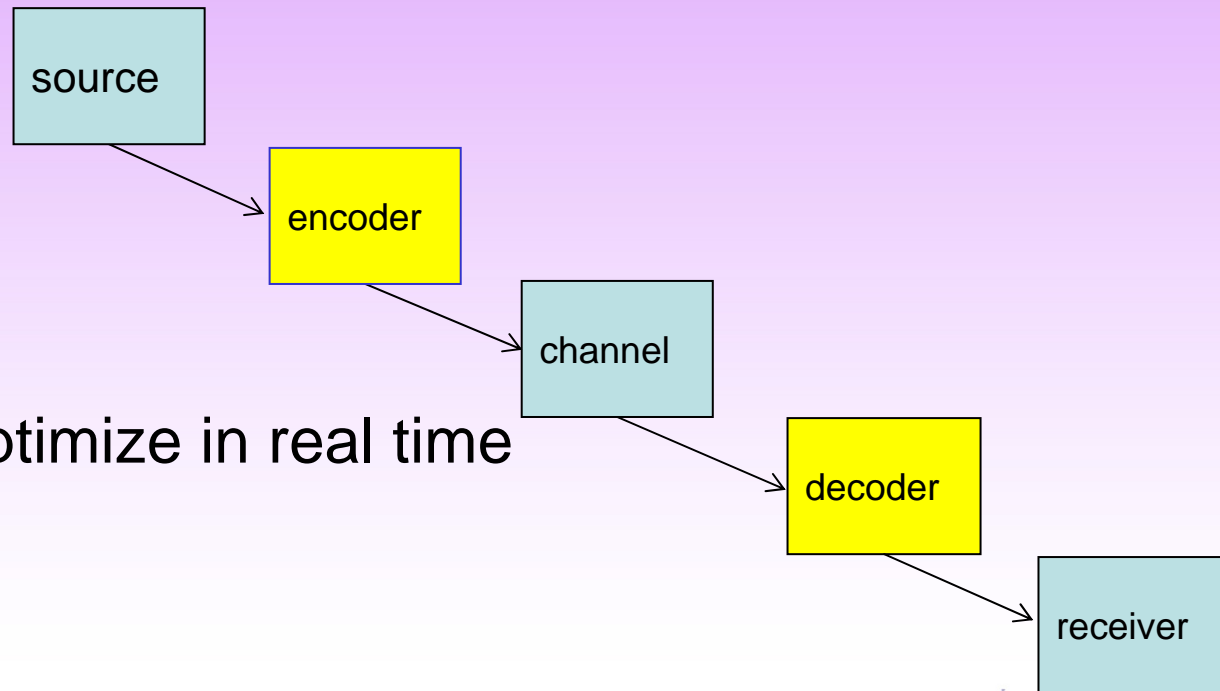
- Audio coder for hearing instruments
 - Real-time scalable
 - Delay < 1 ms; facilitates inter-ear communication
 - Sampling-rate 16 kHz
 - “Design” Rate 32 kb/s
 - Low complexity (processor dependent)
 - Quality better than ITU-T G.722 at 64 kb/s
 - Delay 1.625 ms.



Design Philosophy: *Model Everything*

- Statistical models of

- Source
- Channel
- Receiver
- Encoder
- Decoder



- Estimate / optimize in real time



Real-Time Design Method Based on High-Rate Theory

- Rate-distortion theory (Shannon, 1959)
 - Needs densities; bounds for simple densities only
 - Variable-rate only
 - No direct relation to practical systems
- Lloyd algorithm (Lloyd, 1958)
 - Not a model; leads directly to quantizer
 - Iterative / results in codebooks / not scalable
 - Locally optimal / no need density function
- High-rate theory (Bennett, 1948)
 - Assumes signal density constant in quantization cell
 - Asymptotically optimal
 - Fixed and variable rate
 - Analytic solutions / scalable
 - Provides centroid density / requires additional step



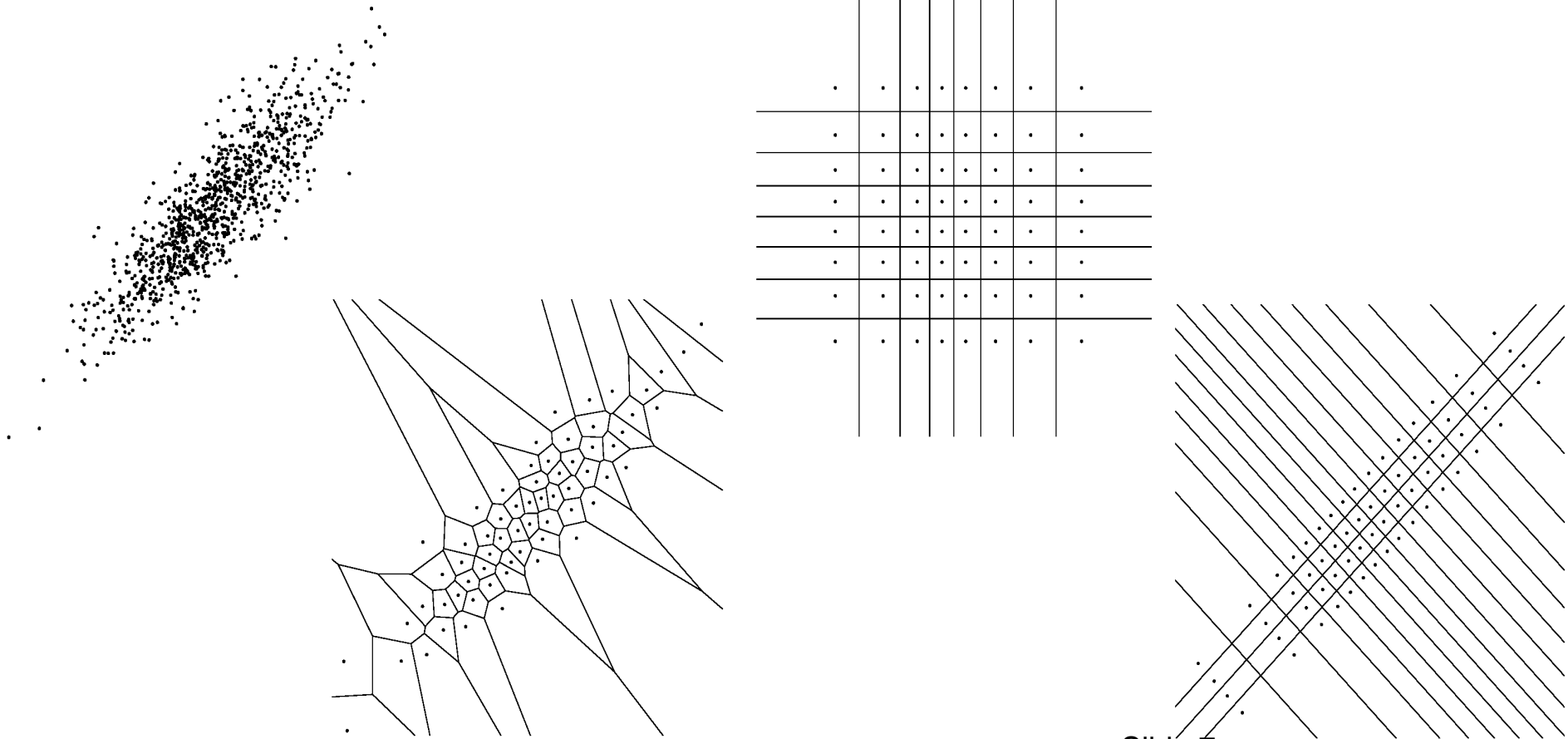
Coder Design Choices

- Signal modeling
 - Predictive coding
 - Transform coding
- Adaptation of the model
 - Backward adaptation
 - Forward adaptation
- Rate or distortion variation
 - Constrained-entropy coding
 - Constrained-resolution coding



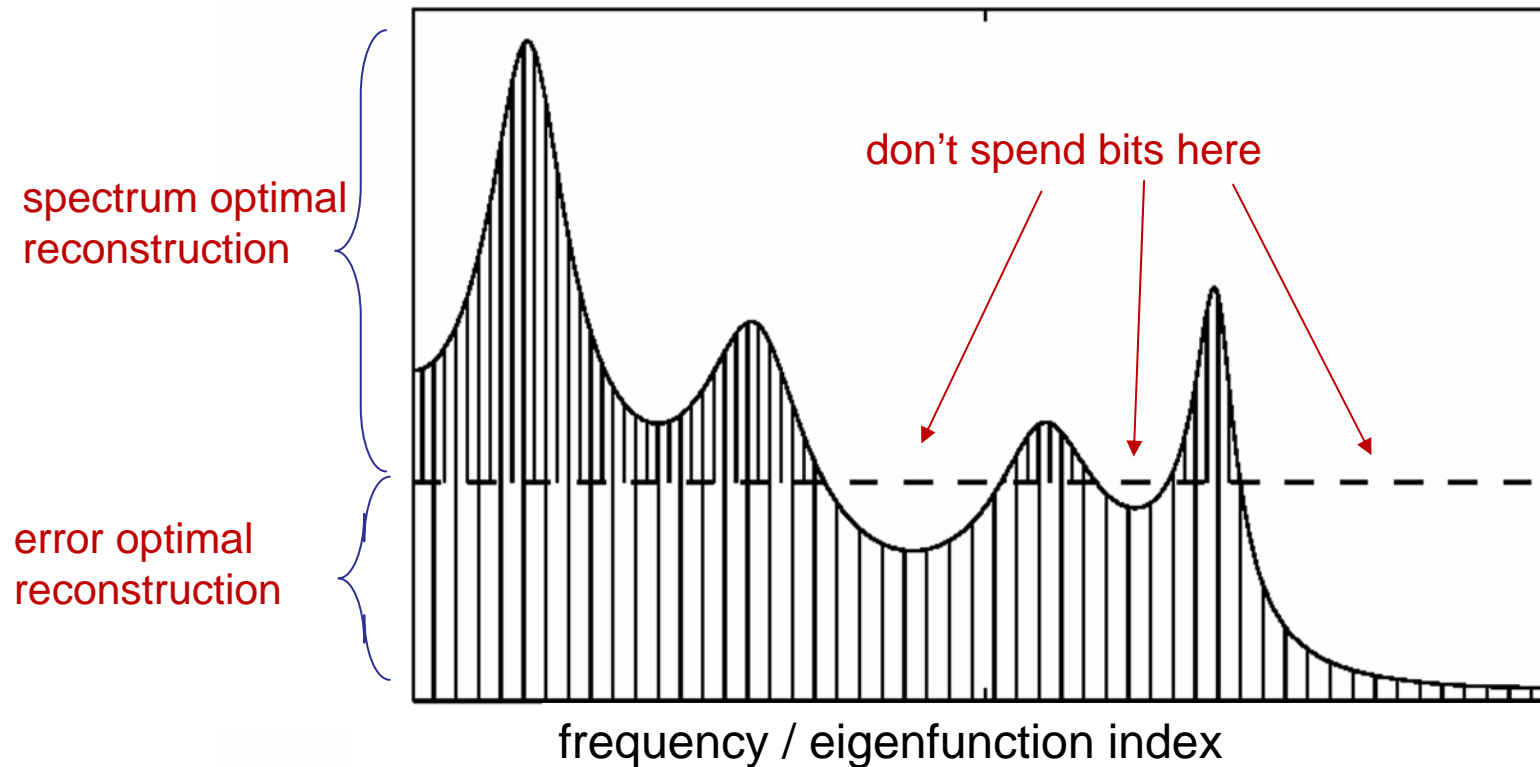
Choices: Prediction vs Transform

- 3-bit/dimension constrained-resolution quantizer



Reverse Waterfilling

- Code only where needed

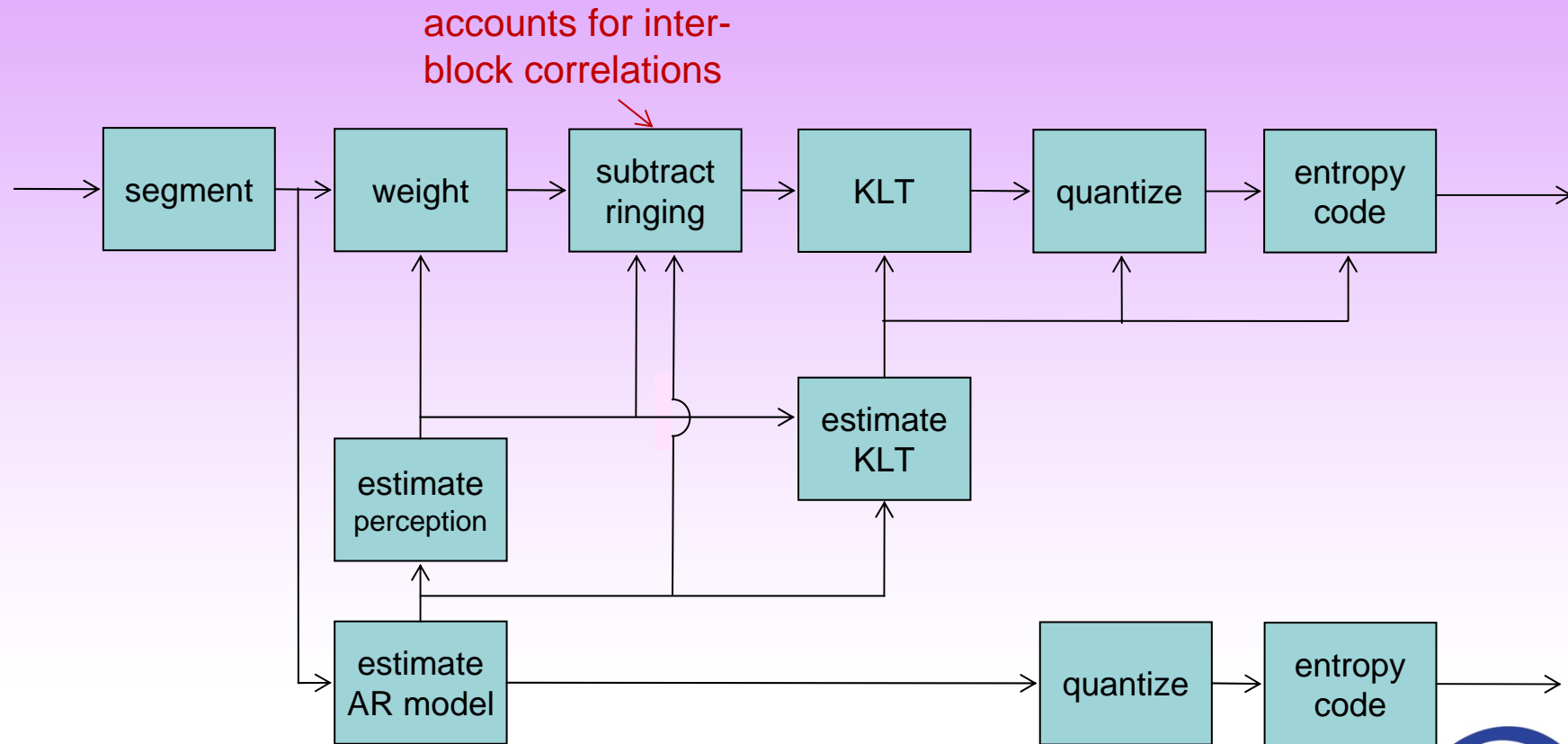


Choices: Modeling

- DCT-based coding: unitary transform
 - Does not affect space-filling
 - Reverse water filling
 - Imperfect decorrelation for fixed transform
 - *Long delay*
- CELP (analysis-by-synthesis AR coder)
 - AR model functions well
 - Inefficient space filling
 - No inherent reverse water filling (requires *post-filter*)
 - Nightmare for adaptive coding



Modeling: Forward Adaptive



Choices: Adaptation

- Forward adaptation

- Estimate model parameters on original signal
- Transmit model parameters
- Requires long blocks

long delay (or estimated on past signal)

- Backward adaptation

- Estimate model parameters on reconstructed signal
- No transmission required
- Frequent update natural -> short delay
- Estimate not accurate after transition

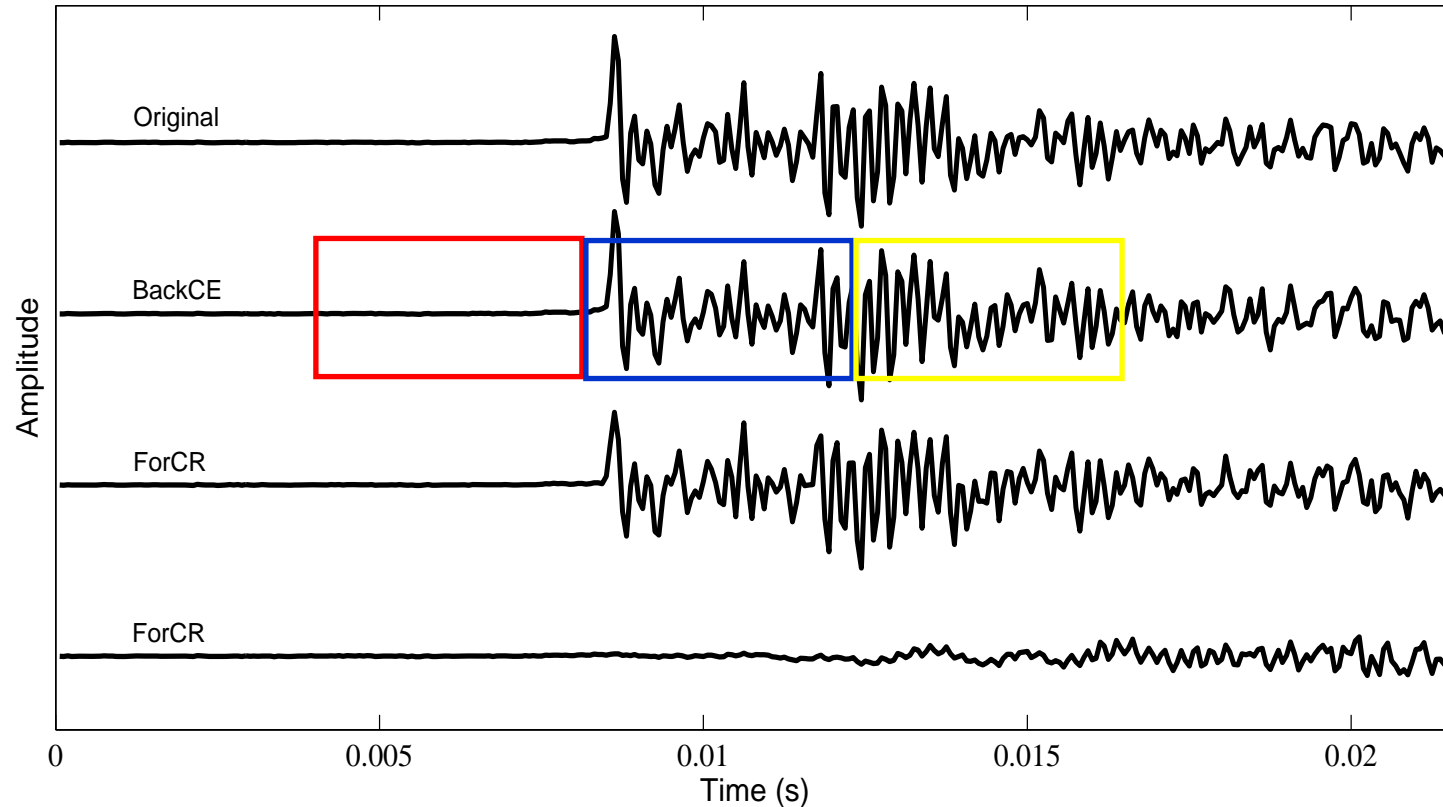


Constrained-Entropy Coding

- Constrained-resolution coding
 - Fixed rate
 - Outliers in distortion → leads to error feedback in backward adaptation
- Constrained-entropy coding
 - “Fixed” distortion → No error feedback in backward adaptation!
 - Outliers in rate



Illustration: Backward Adapt and CE



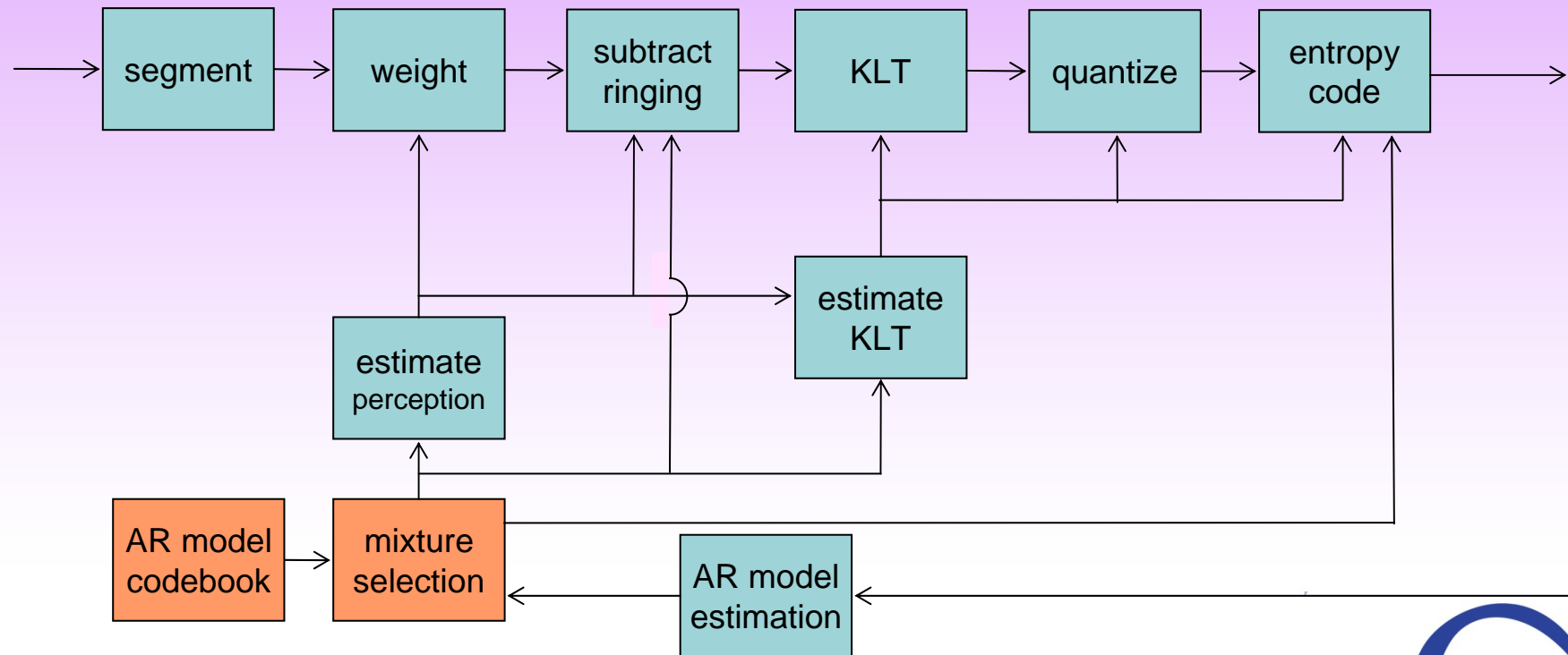
- Constrained entropy = fixed distortion
- Same average rate

Constrained-Entropy Coding

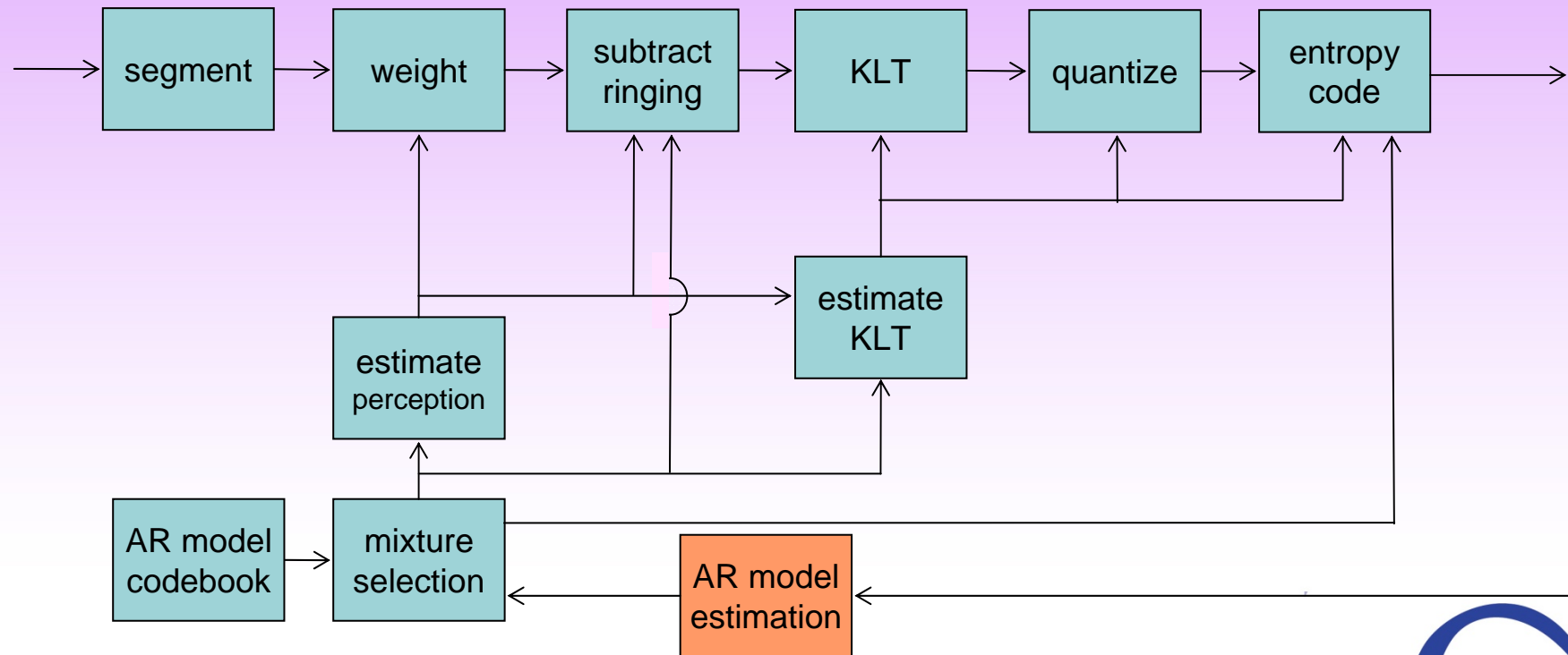
- Constrained resolution coding
 - Fixed rate
 - Outliers in distortion → leads to error feedback in backward adaptation
- Constrained entropy coding
 - “Fixed” distortion → No error feedback in backward adaptation!
 - Outliers in rate → generally very bad rate variation



Removal Rate Outliers



Improved Backward Model Estimation



Workshop Hearing Screening and Technology, Brussels 28 January 2009



Slide 17



HEARCOM Coder Architecture

- KLT modeling:
 - Better than CELP
 - Better than MDCT
- Backward-adaptive, variable rate
 - Very short delay
 - Constant quality
 - No feedback of distortion
 - Limited rate variation
 - Enhanced model estimation



Comparative Quality and Rate

- MUSHRA (MUltiple Stimuli with Hidden Reference and Anchor) test
- HEARCOM coder is *scalable!*

coder	Rate (kb/s)	Delay (ms)	MUSHRA score
ITU-T G.722	64	1.625	69.6
ITU-T-G.722	48	1.625	56.9
HEARCOM	32*	0.625	71.3



Conclusions

- Architecture determines effectiveness low-D coding
 - CELP not naturally scalable
 - MDCT has long delay, imperfect decorrelation
 - KLT-based architecture performs best
- HEARCOM coder attributes:
 - Scalable: can redesign coder in real time at any time
 - Given quality: reduces rate of G.722 by factor two
 - **Very low delay (0.625 ms)**
 - Low computational complexity
 - Architecture can also be used for forward-adaptive approach
 - Facilitates multiple-description coding
 - Coder is programmed in C

