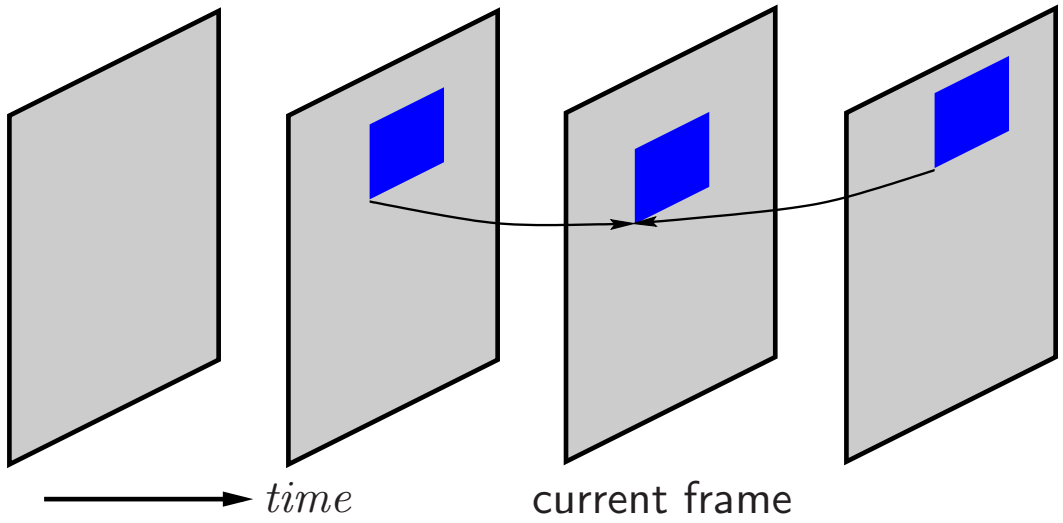
Data Compression Conference 2001

Multihypothesis Motion Estimation for Video Coding

Markus Flierl
Telecommunications Laboratory
University of Erlangen-Nuremberg
flierl@LNT.de

Bernd Girod
Information Systems Laboratory
Stanford University
girod@ee.stanford.edu

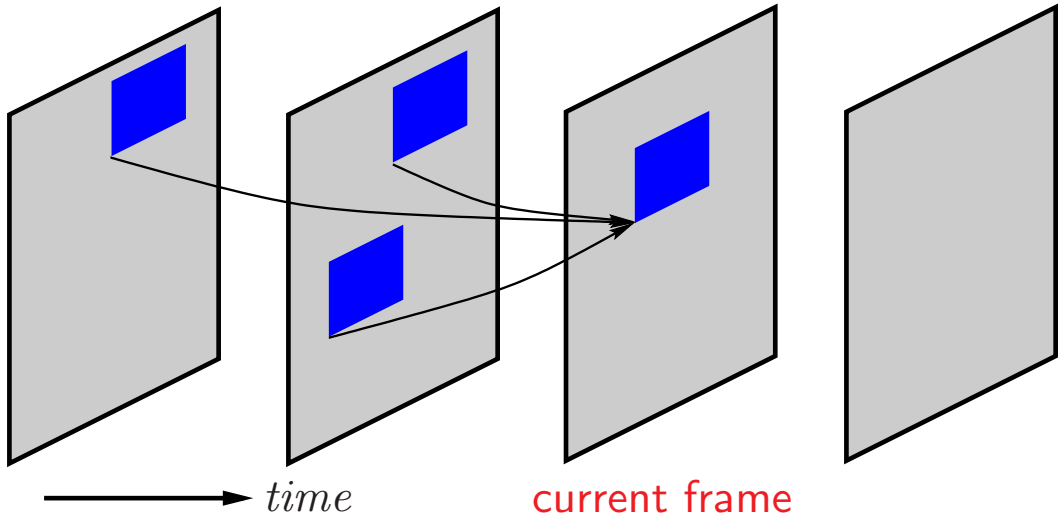
Bidirectional Prediction for B Pictures



- Joint estimation of forward and backward motion vectors [Wu and Gersho, 1994]

Multihypothesis Motion-Compensated Prediction

- Linear combination of multiple motion-compensated signals



- Joint estimation of multiple hypotheses [Flierl, Wiegand, and Girod, 1998]

This Talk ...

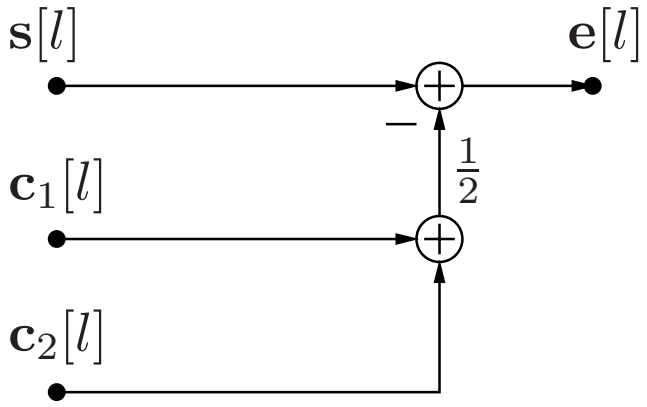
will extend an analytical model for multihypothesis motion-compensated prediction [Girod, 2000]

- Capture a property of jointly estimated motion-compensated signals
- Investigate the gains of optimal hypothesis sets.

Overview

- Model for multihypothesis motion compensation
- Modeling the joint displacement error PDF
- Optimal multihypothesis motion estimation
- Hypotheses with additive noise

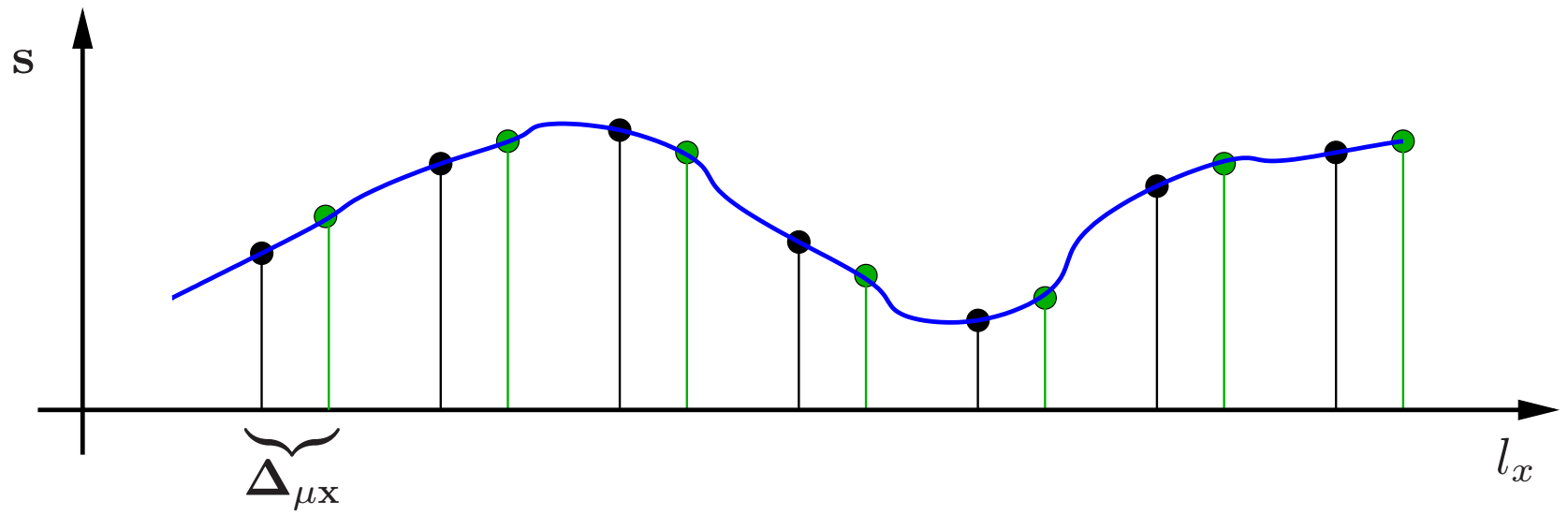
Model for Multihypothesis Motion Compensation



$\mathbf{s}[l]$	current frame signal
$\mathbf{c}_\mu[l]$	μ-th hypothesis
$\mathbf{e}[l]$	prediction error

- All hypotheses $\mathbf{c}_\mu$ are shifted versions of the current frame signal $\mathbf{s}$
- Prediction error results from motion inaccuracy only
- Hypotheses are just averaged

Model for Multihypothesis Motion Compensation



- The shift is determined by the displacement error $(\Delta_{\mu x}, \Delta_{\mu y})$ of the μ-th hypothesis

- The ideal reconstruction of the band-limited signal $s[l]$ is shifted by the continuous valued displacement error

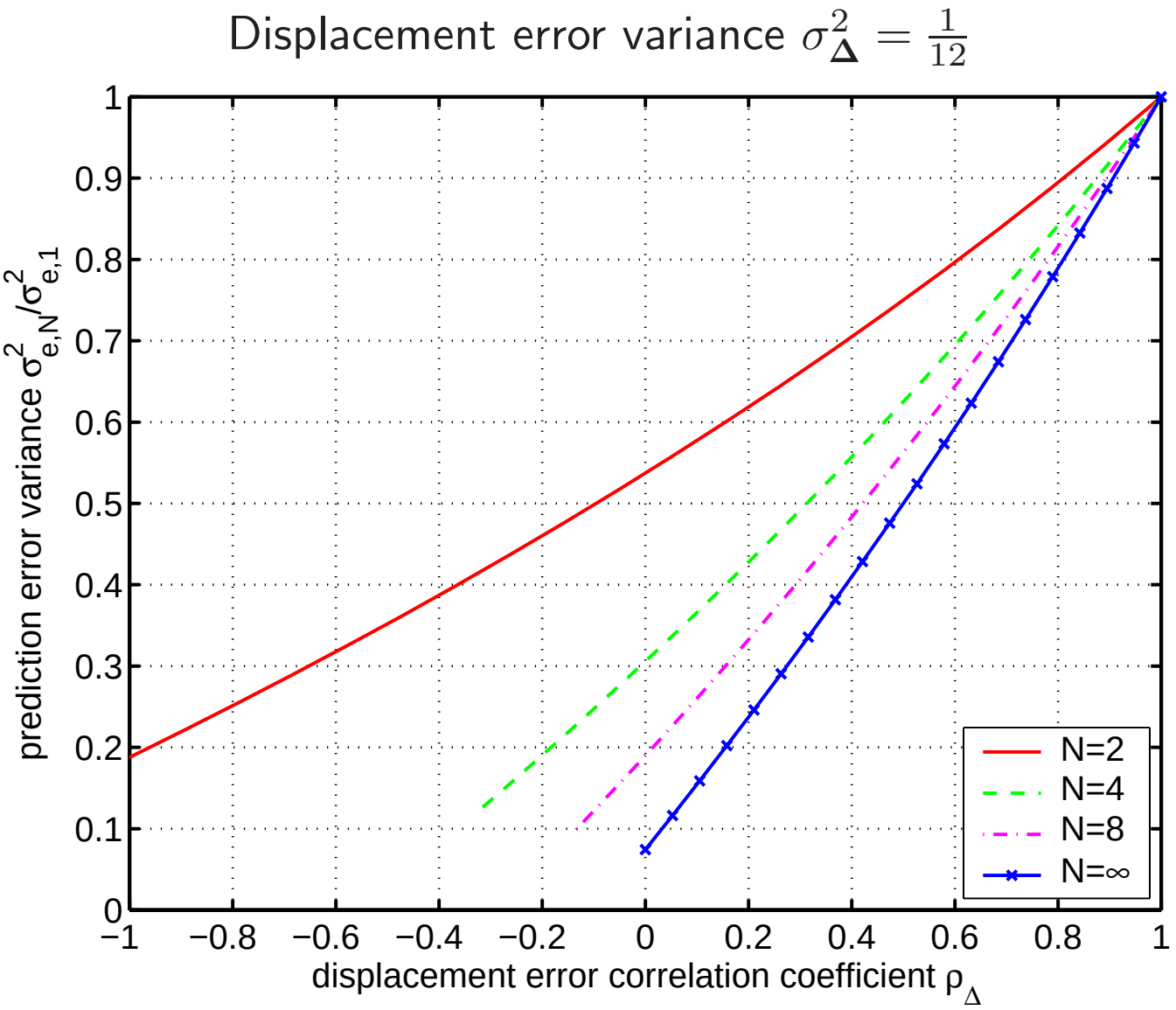
Modeling the Joint Displacement Error PDF

- 2-D stationary normal distribution with variance $\sigma^2_{\boldsymbol{\Delta}}$ and zero mean for each hypothesis
- x- and y-components are statistically independent
- Each displacement error pair is assumed to be jointly Gaussian with no preference among the N hypotheses
- Covariance matrix of a displacement error component:

$$C_{\boldsymbol{\Delta}_x\boldsymbol{\Delta}_x} = C_{\boldsymbol{\Delta}_y\boldsymbol{\Delta}_y} = \sigma^2_{\boldsymbol{\Delta}} \begin{pmatrix} 1 & \rho_{\boldsymbol{\Delta}} & \cdots & \rho_{\boldsymbol{\Delta}} \\ \rho_{\boldsymbol{\Delta}} & 1 & \cdots & \rho_{\boldsymbol{\Delta}} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{\boldsymbol{\Delta}} & \rho_{\boldsymbol{\Delta}} & \cdots & 1 \end{pmatrix}$$

- Covariance matrix is nonnegative definite: $\dfrac{1}{1-N} \leq \rho_{\boldsymbol{\Delta}} \leq 1$

Prediction Error vs. Displacement Error Correlation



Decreasing displacement error correlation reduces prediction error variance

Optimal Multihypothesis Motion Estimation

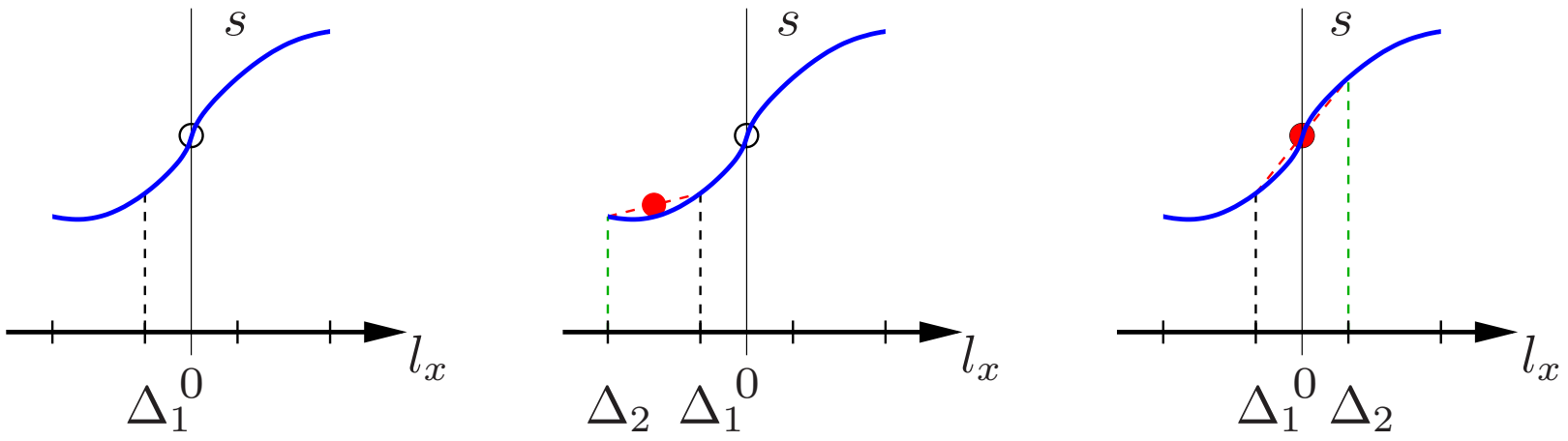
- The optimal multihypothesis motion estimator in the MSE sense minimizes the prediction error variance.

- Consequently, the optimal estimator minimizes also the displacement error correlation coefficient:

$$\rho_{\mathbf{\Delta}} = \frac{1}{1-N} \quad \text{for} \quad N = 2, 3, 4, \ldots$$

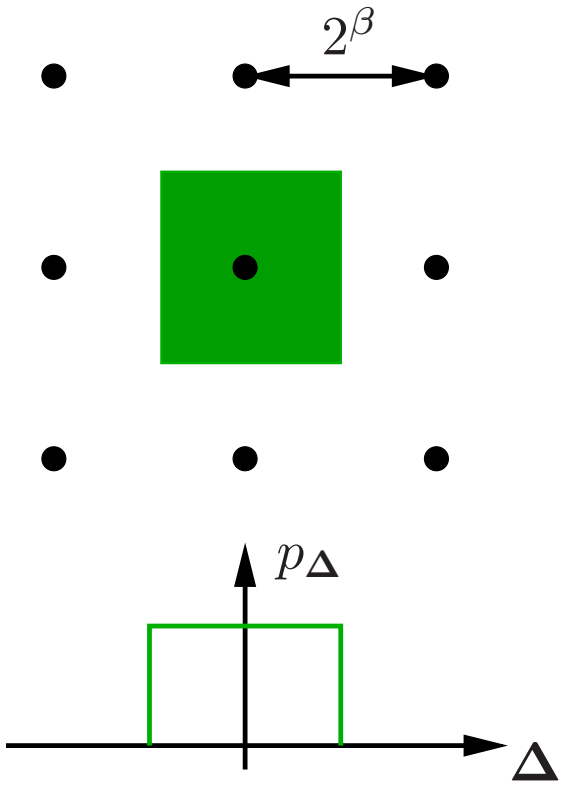
Maximally negatively correlated displacement errors

Maximally Negatively Correlated Displacement Errors



- Displacement error $\boldsymbol{\Delta_1}$ due to quantization
- How to select the second hypothesis?
- $\boldsymbol{\Delta_2} = -\boldsymbol{\Delta_1} \rightarrow \rho_{\boldsymbol{\Delta}} = -1$

Displacement Inaccuracy



$\beta = 0$: integer-pel accuracy

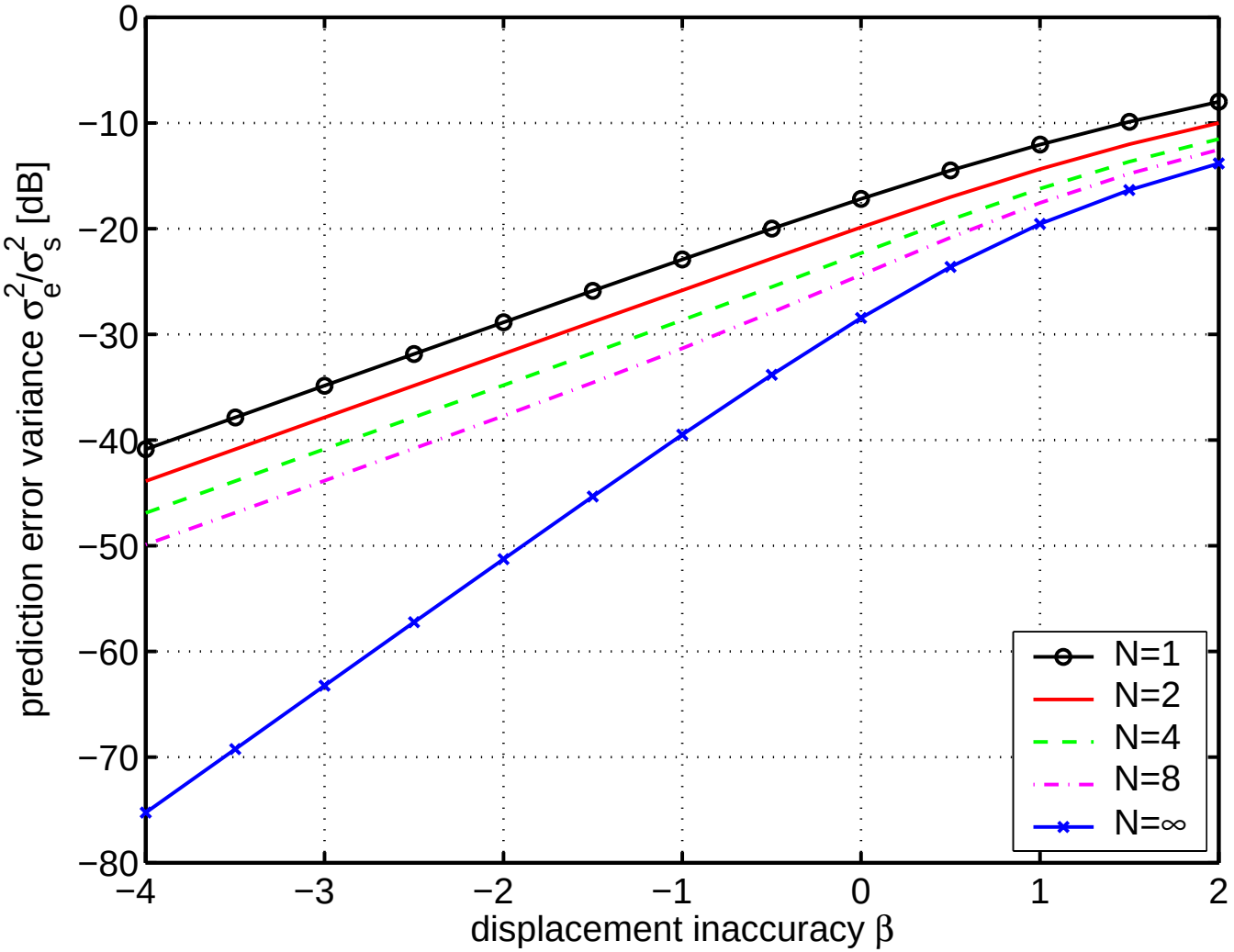
$\beta = -1$: half-pel accuracy

$\beta = -2$: quarter-pel accuracy

$$\sigma_\Delta^2 = \frac{2^{2\beta}}{12}$$

The displacement error is entirely due to rounding and is uniformly distributed.

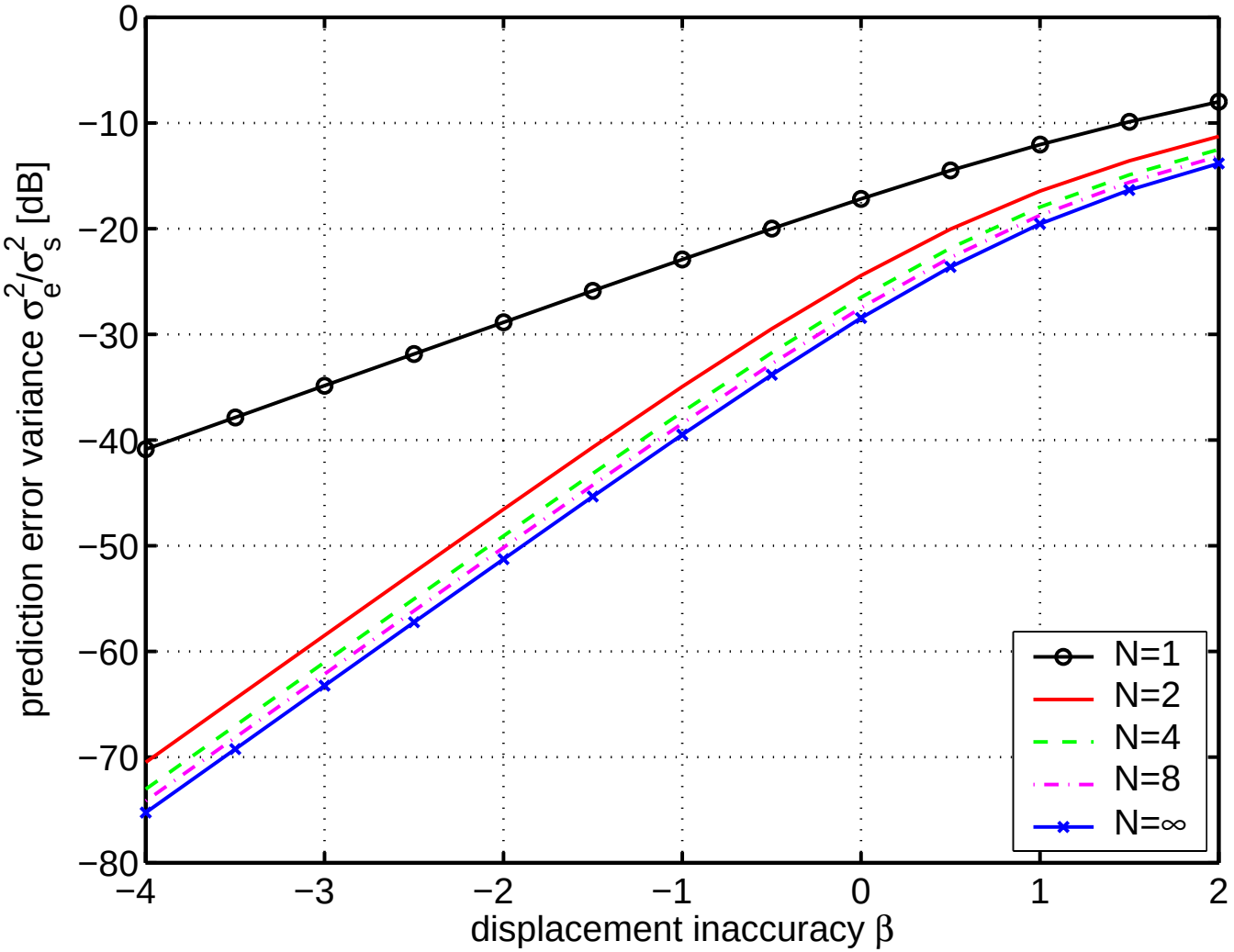
Multihypothesis Motion Estimation I



Uncorrelated displacement errors $\rho_{\mathbf{\Delta}} = 0$

Slope of 12 dB per inaccuracy step for $N = \infty$

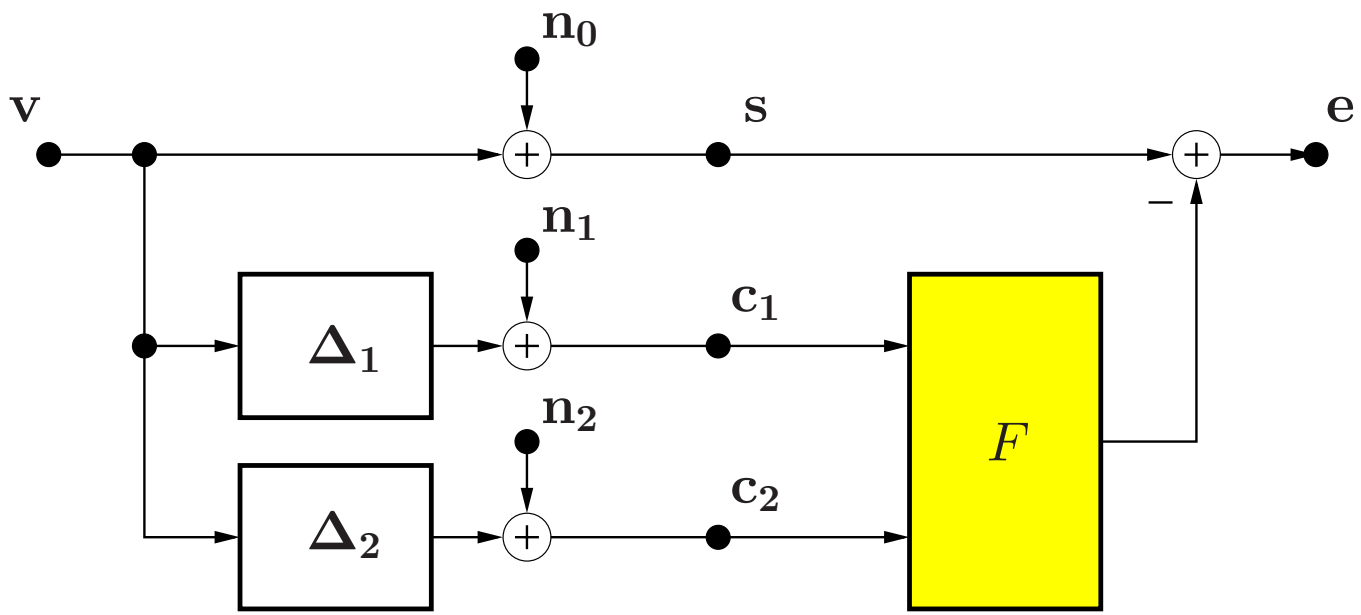
Multihypothesis Motion Estimation II



Optimized displacement error correlation $\rho_{\Delta} = \frac{1}{1-N}$

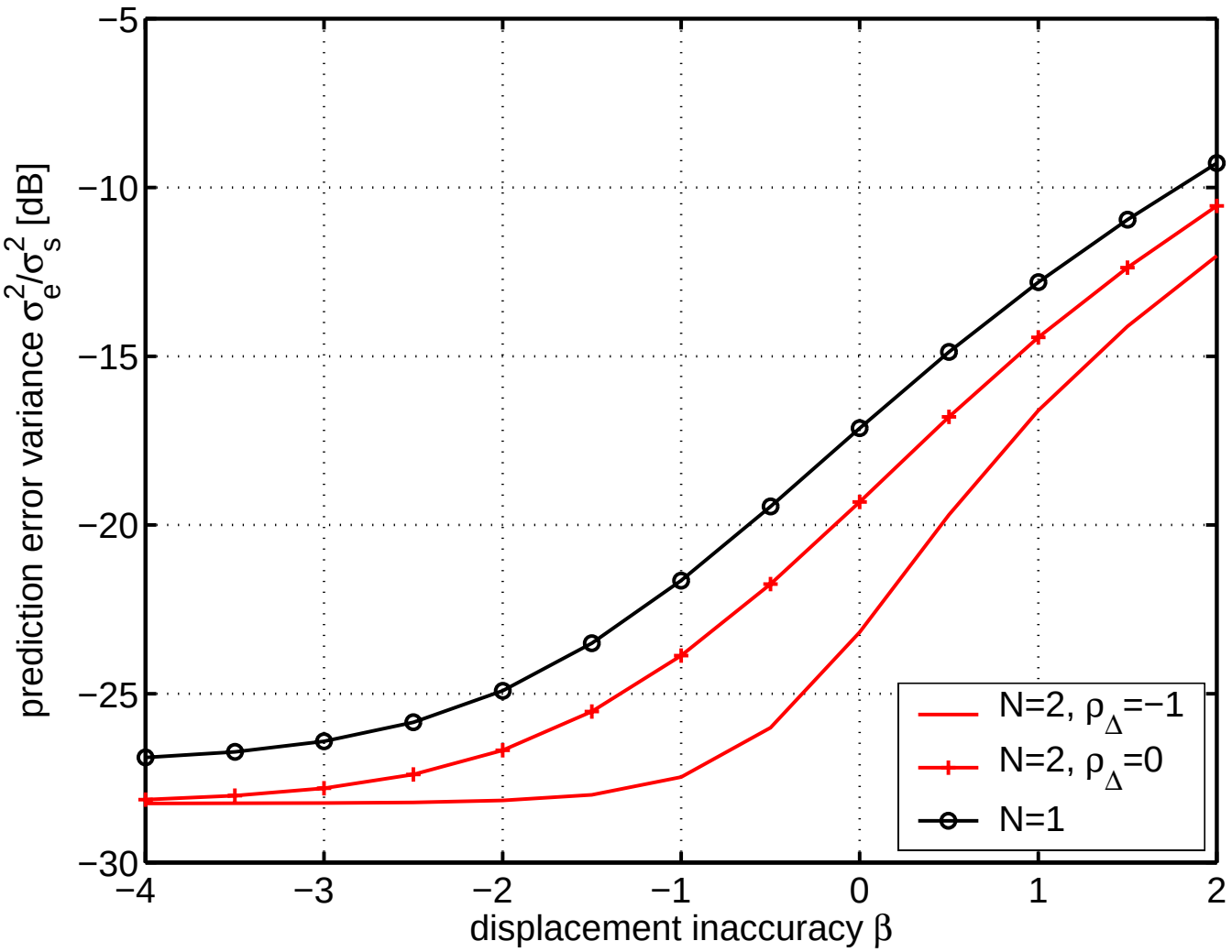
Slope of 12 dB per inaccuracy step is already reached for $N = 2$

Hypotheses with Additive Noise



- Current frame signal $\mathbf{s}$ originates from a "clean" video signal $\mathbf{v}$
- Noise signals $\mathbf{n}_\mu$ are mutually statistically independent

Hypotheses with Additive Noise



Band-limited frame signal, residual noise level RNL $= 10\log_{10}(\sigma_n^2) = -30$dB

Summary and Conclusions

- We discussed the efficiency of multihypothesis motion compensation dependent on the estimated hypothesis set.

- Optimal multihypothesis motion estimation results in maximally negatively correlated displacement errors.

- In the case of "noisy" hypotheses, we obtain improved prediction performance for optimal multihypothesis motion estimation with the optimum Wiener filter.