# Asymptotic Closed-Loop Design for Transform Domain Temporal Prediction

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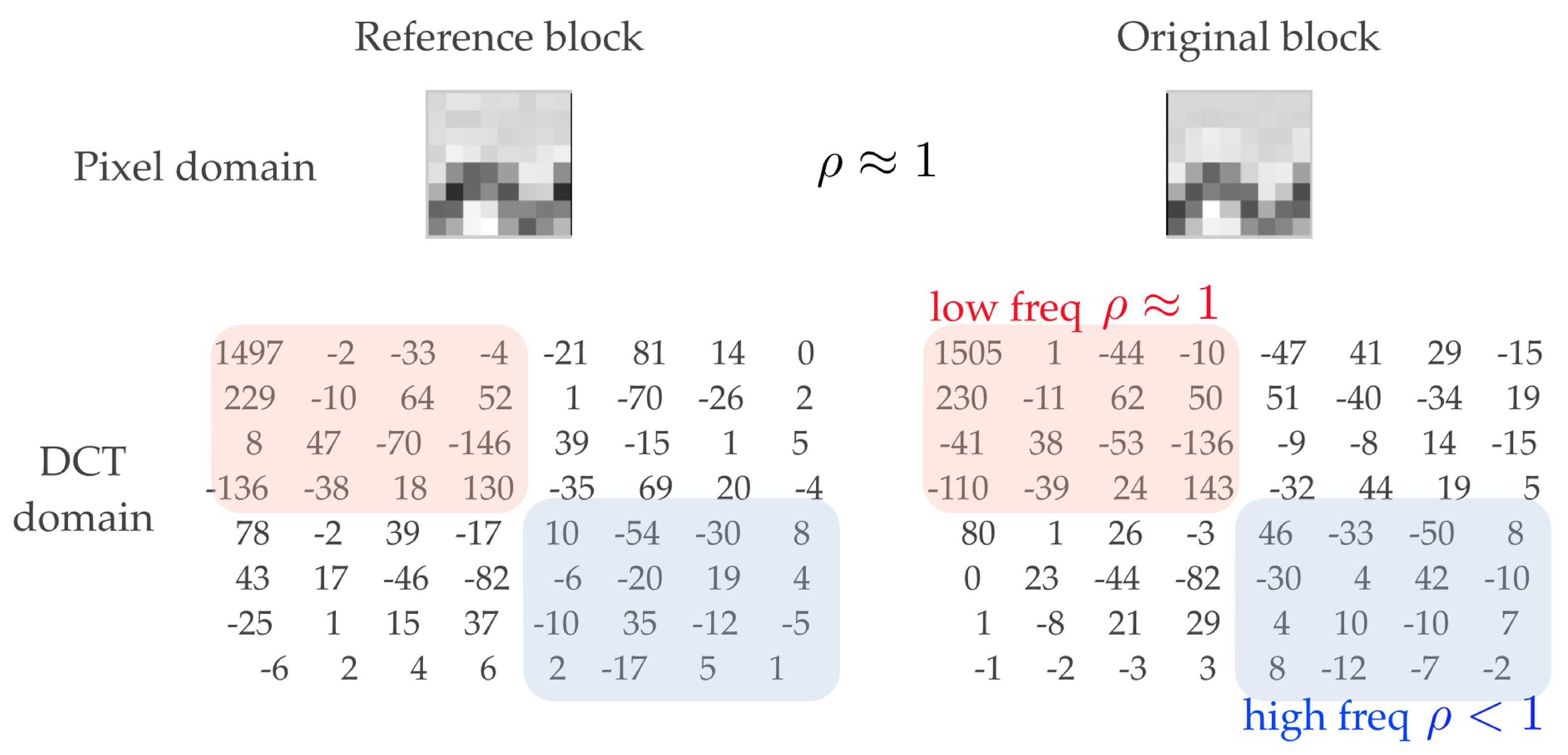
## Transform Domain Temporal Prediction (TDTP)

### Pixel-Domain Inter Prediction is Suboptimal

- Traditional inter prediction copies pixels one-by-one.
- Suboptimal because it ignores spatial correlation.
- Transform Domain Temporal Prediction (TDTP): DCT (largely) achieves spatial decorrelation, enabling optimal one-to-one prediction.

### Hidden Temporal Correlation at High Frequency




- Correlation in pixel domain is dominated by the low frequencies ($\rho \approx 1$), inspiring the traditional pixel copying prediction.
- TDTP: Accounts for variation in temporal correlation across frequency, which is hidden in pixel domain.

### Sub-Pixel Motion Compensation Interferes with TDTP

- The interpolation low-pass filters scale down high-frequencies as per its magnitude response.
- Thus we apply TDTP conditioned on the sub-pixel location.

## Closed-Loop Predictor Design

- The optimal predictor for each transform domain coefficient is given by,

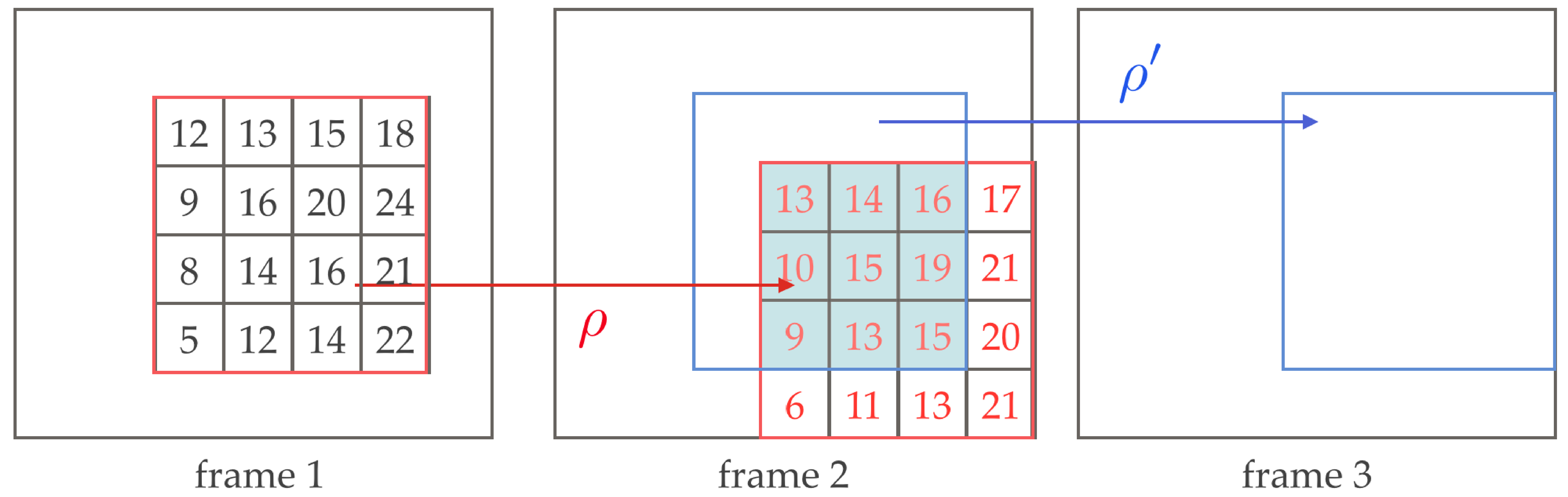
$$\tilde{x}_n = \rho \hat{x}_{n-1}$$

- Given the motion compensated reference blocks, the optimal prediction coefficient is the correlation coefficient,

$$\rho = \frac{E(x_n \hat{x}_{n-1})}{E(\hat{x}^2_{n-1})}$$

## Instability Due to Quantization Error Propagation

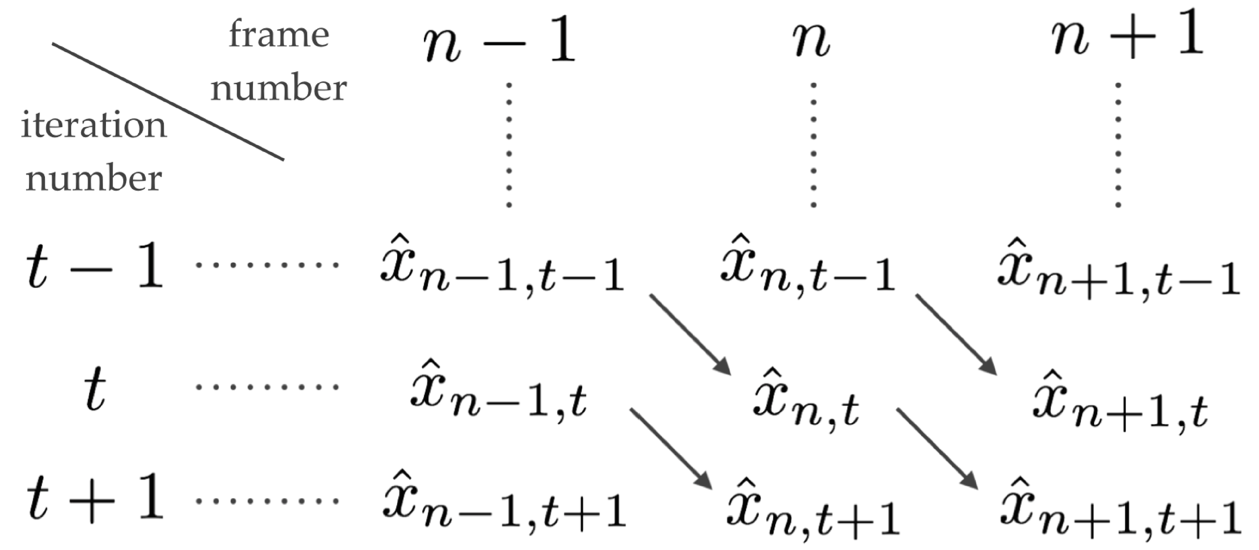
- As we operate this predictor in closed loop, the new reconstructed frames (which are prediction reference for future frames) have different statistics, for which the correlation coefficient $\rho' \neq \rho$.




- This deviation in statistics between design and operation grows over frames.
- Thus we propose the asymptotic closed-loop (ACL) design approach for TDTP.

## Asymptotic Closed-Loop (ACL) Design

- ACL is an iterative open-loop design technique that asymptotically optimizes the system for closed-loop operation.



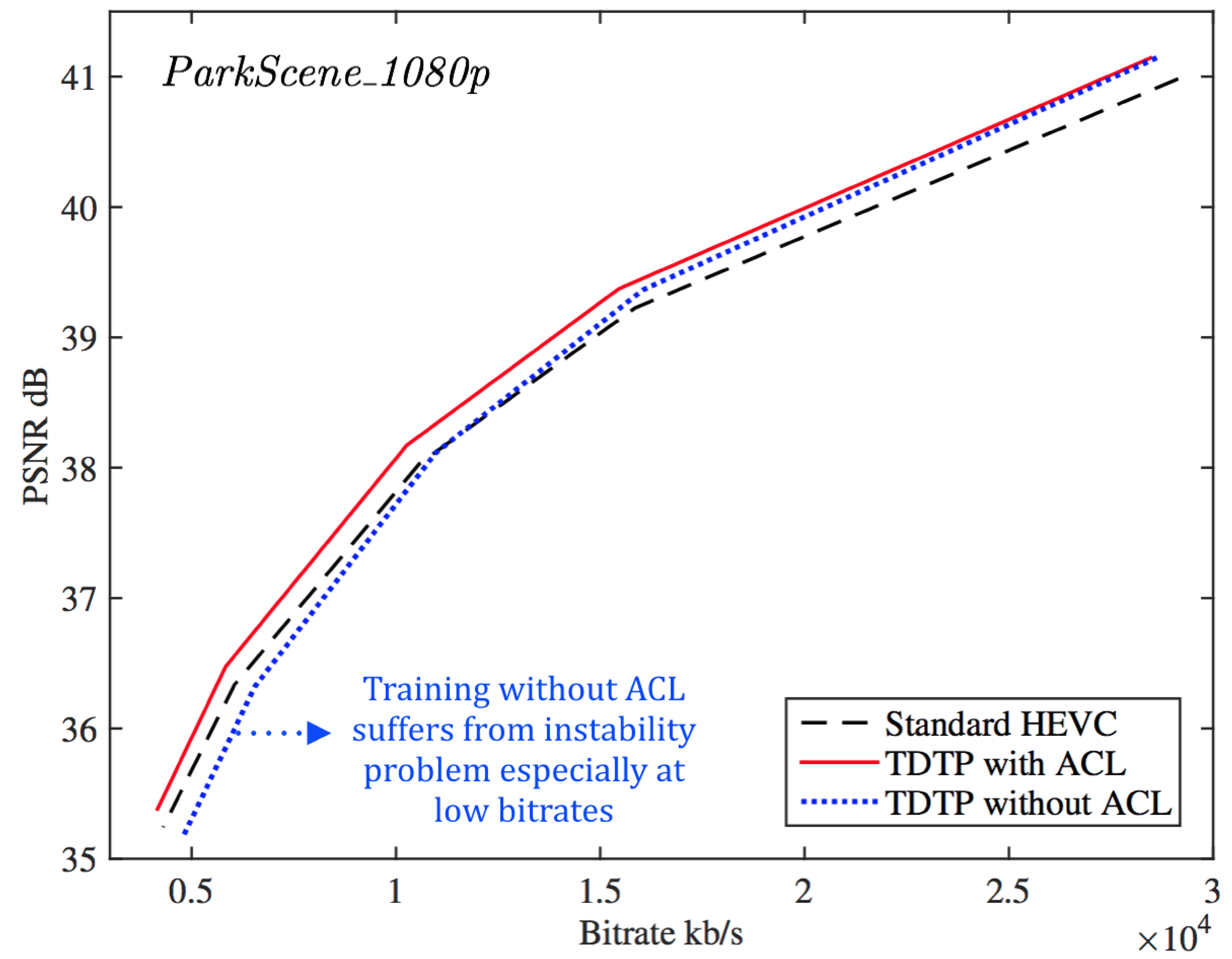

- Given the reconstructed data at iteration $t-1$, $\hat{x}_{n-1,t-1}$ ($n = 2 \dots N$), estimate the prediction coefficient for iteration $t$ as, $\rho_t = E(x_n \hat{x}_{n-1,t-1})/E(\hat{x}^2_{n-1,t-1})$.
- Then employ open-loop prediction to generate, $\tilde{x}_{n,t} = \rho_t \hat{x}_{n-1,t-1}$.
- Since $\rho_t$ is directly optimized for the statistics of $\hat{x}_{n-1,t-1}$ ($n = 2 \dots N$), the prediction $\tilde{x}_{n,t}$ is guaranteed to improve.
- Better prediction usually leads to better reconstruction, $\hat{x}_{n,t}$, and vice versa.
- The reconstruction error decreases over iterations and on convergence, $\hat{x}_{n,t-1} = \hat{x}_{n,t}$, which is equivalent to the closed-loop system.

## Two Loop Asymptotic Closed-Loop (ACL) Design for TDTP

- In video coding, encoder decisions (e.g. mode decisions, motion vectors, quantization, etc.) are dependent on the prediction.
- Thus we proposed a two-loop design scheme:
  Inner loop: Estimate prediction coefficient $\rho$ via ACL with encoder decisions fixed.
  Outer loop: Update encoder decisions with $\rho$ fixed.
- We design different prediction coefficients conditioned on: sub-pixel location, quantization parameter (QP), skip/non-skip mode

## Experimental Results

- The proposed approach was implemented in HM 14.0. Both prediction size and transform size are restricted to 8x8, and the motion search is at half-pixel precision.
- The average bitrate reduction over standard HEVC is 6.53% for training set (Exp1) and 4.96% outside training set (Exp2).
- In Exp2 we provide a choice of 8 sets of prediction coefficients at the encoder with an overhead of 3 bits per sequence. The difference between the two experiments suggests further scope for adaptivity.




| Sequence | Exp1 | Exp2 | Sequence | Exp1 | Exp2 |
|---|---|---|---|---|---|
| BQTerrrace | 12.88% | 10.23% | Waterfall | 9.29% | 4.38% |
| BasketballDrive | 6.21% | 5.36% | Vidyo1 | 5.75% | 4.56% |
| Kimono | 7.88% | 4.53% | Bus | 5.59% | 5.37% |
| ParkScene | 7.41% | 7.00% | Tennis | 2.23% | 1.50% |
| Keiba | 5.38% | 5.17% | Tempete | 5.56% | 5.30% |
| RaceHorse | 3.44% | 3.03% | FourPeople | 6.81% | 3.04% |

This work was supported in part by a gift from LG Electronics Inc.
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