Design of Multimedia Applications: Error Concealment in Digital Video

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Introductory Lectures and Exercises

- Two introductory lectures
  - "error concealment" and "Video on Demand player"
  - independent of theory lectures
  - background information

- Exercises
  - under supervision in Technicum: RTB Les 2.14 every Monday, from 16h00 till 18h45
    - attendance not mandatory

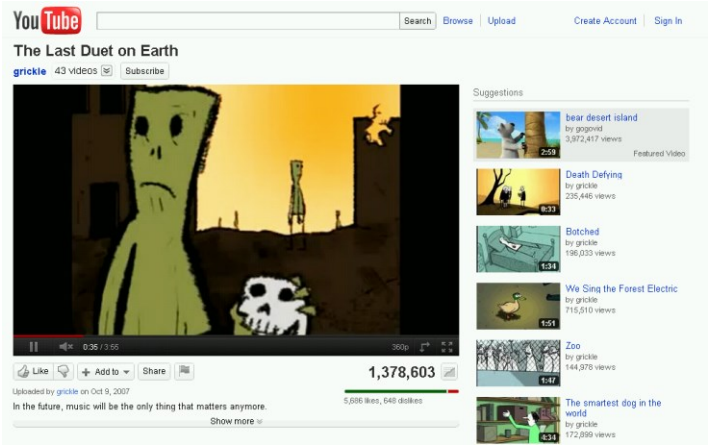
Outline

- Introduction
- Error concealment strategies
- Passive error concealment
  - spatial error concealment
  - temporal error concealment
- Video quality measurement

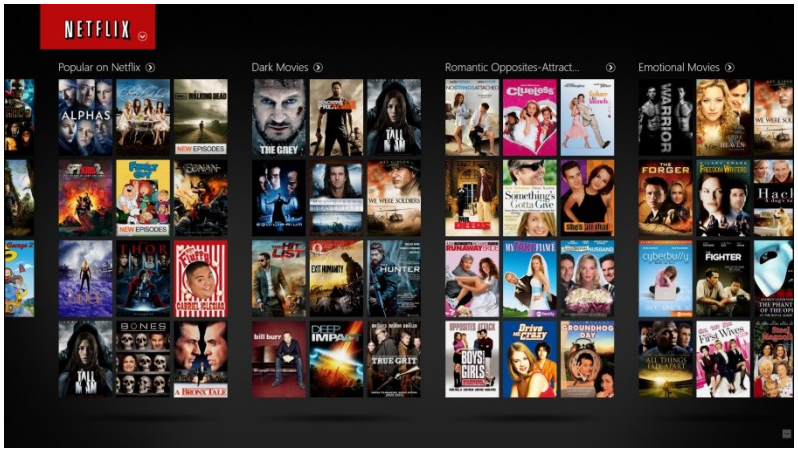
- Assignment

Introduction

- Transport of video over networks
  - increasing importance
  - enabled by video compression (a/o technologies)

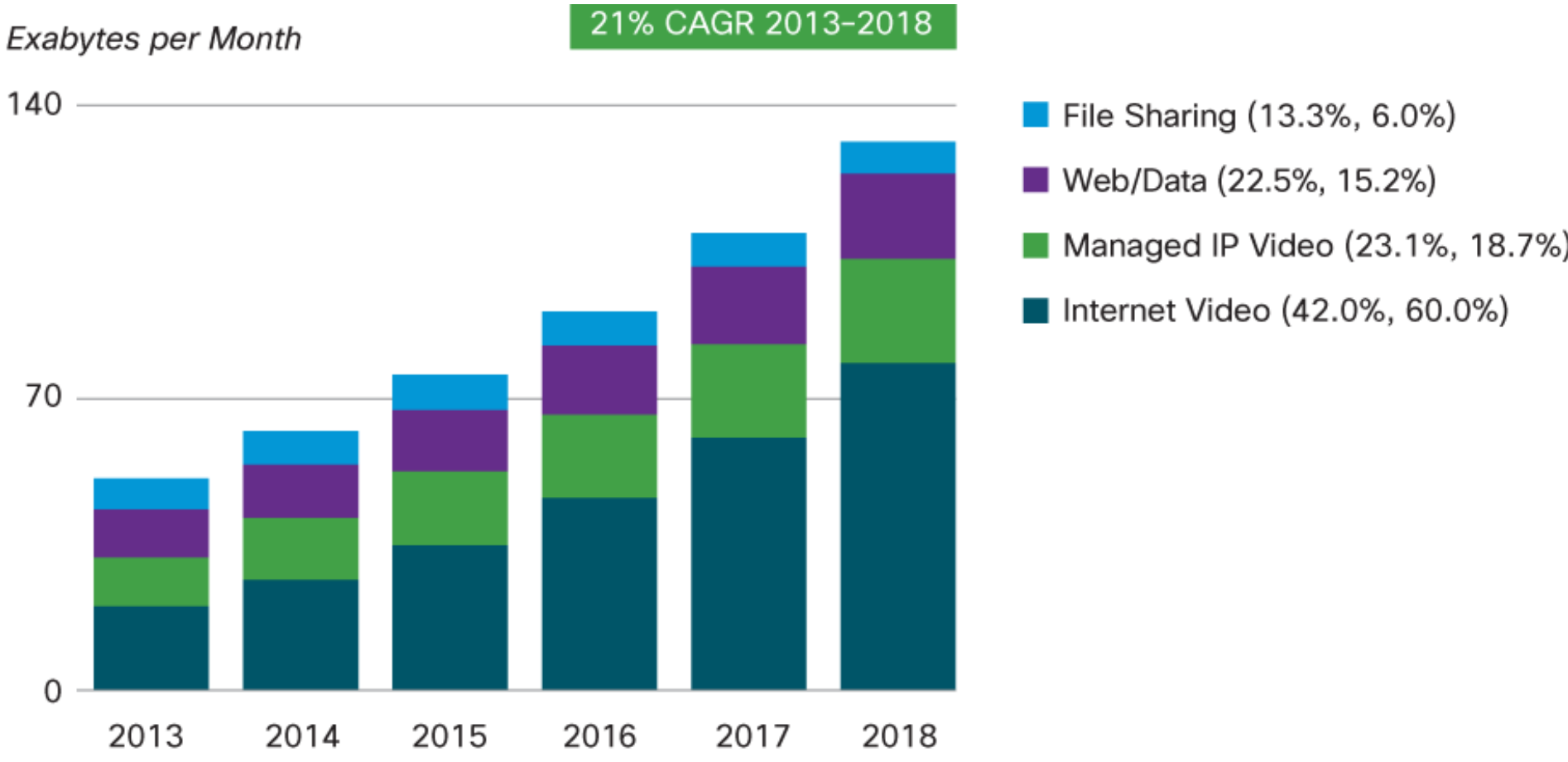


- YouTube sees 100 hours of video content uploaded every minute



- Netflix streams over 114,000 years of video every month

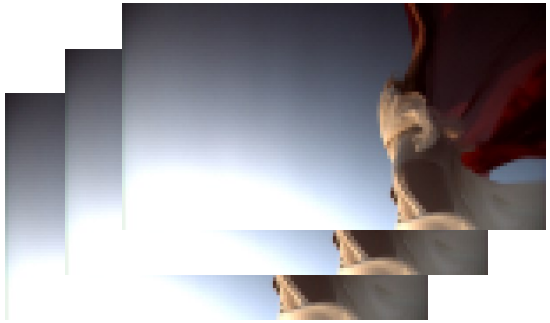
Videodata becomes even more important



Source: Cisco VNI, 2014

The percentages within parentheses next to the legend denote the relative traffic shares in 2013 and 2018, respectively.

System for Video Compression



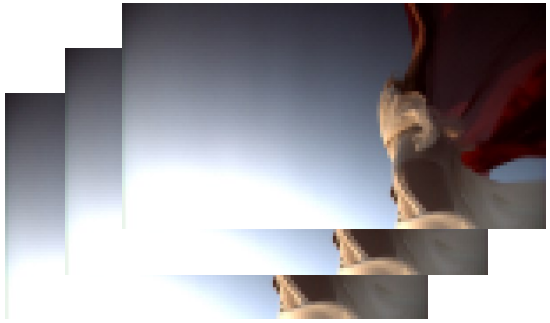
530.84 Mbps
(720p@24Hz)

Encoder

Compressed video

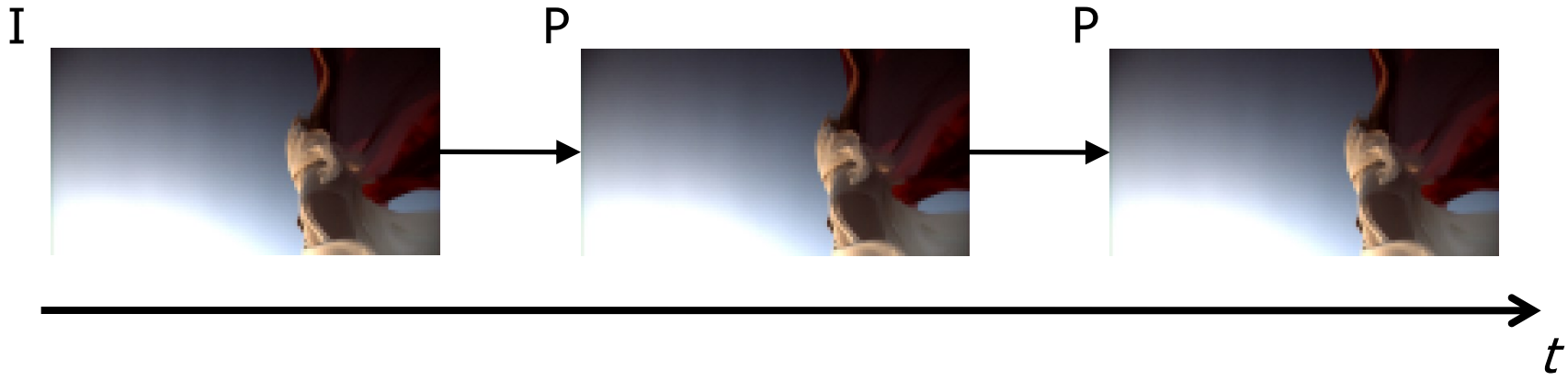
1.5 Mbps

Decoder



530.84 Mbps

Structure of a Video Sequence



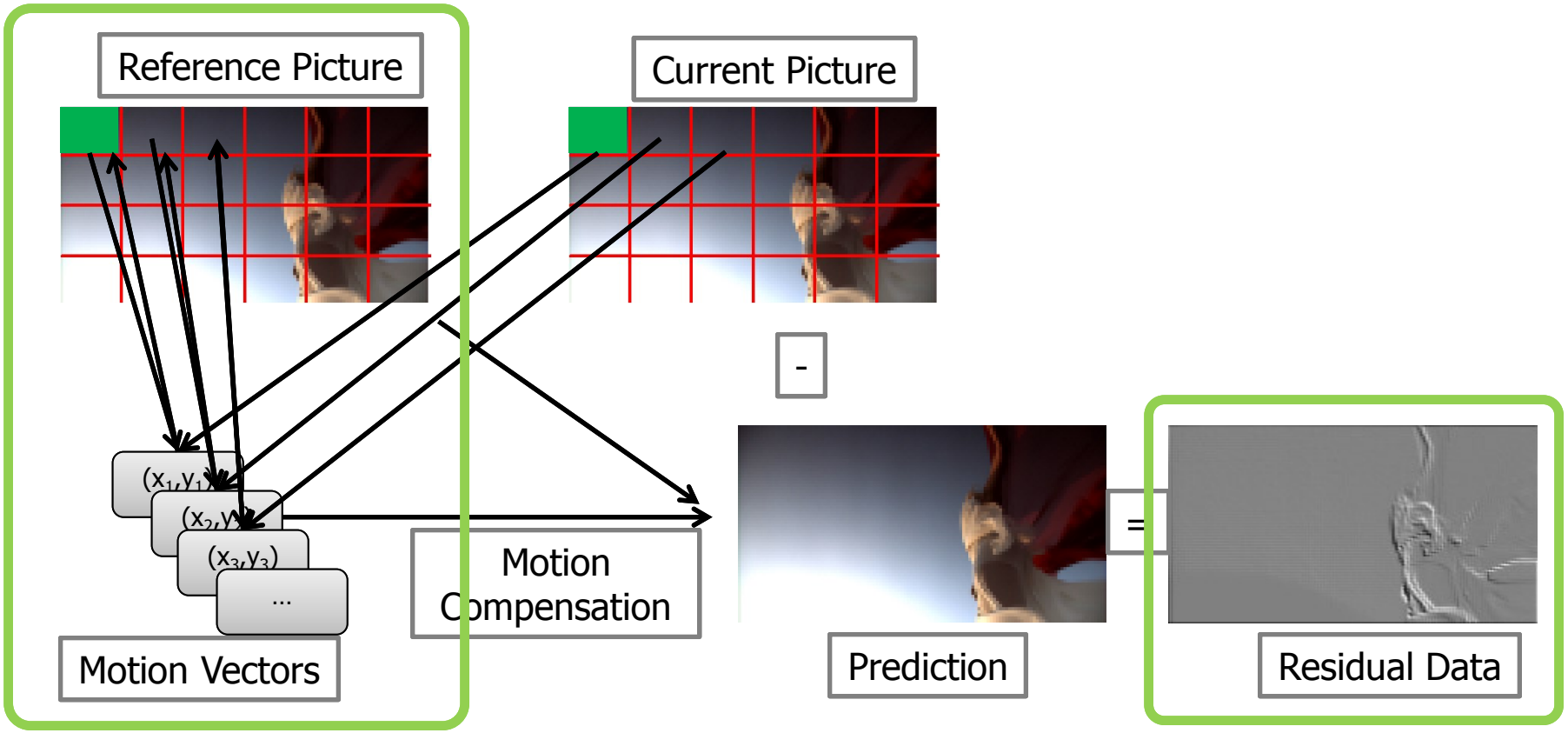
- Video sequence
  - a series of frames that change over time
  - contains two types of compressed frames
    - keyframes: independently coded (I frames)
    - difference frames: predictively coded (P frames)

Computation of Difference Frames

- Straightforward approach
  - subtract the previous frame from the current frame

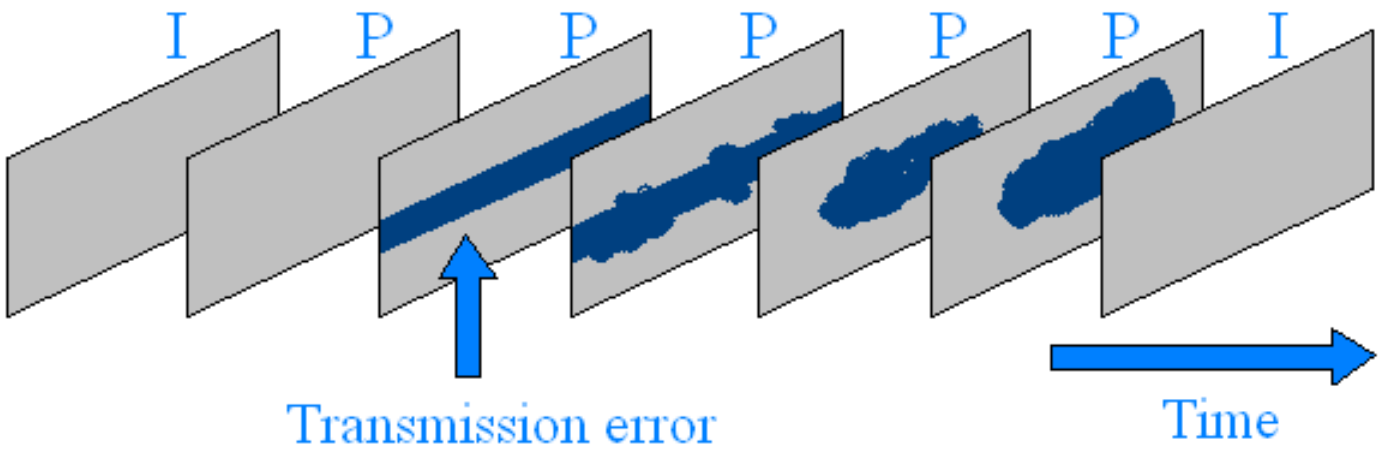
- Better approach
  - predict the change between two consecutive frames
    - by making use of
      - block-based motion estimation
      - block-based motion compensation
    - results in difference frames with less energy (entropy)

Motion Estimation and Compensation

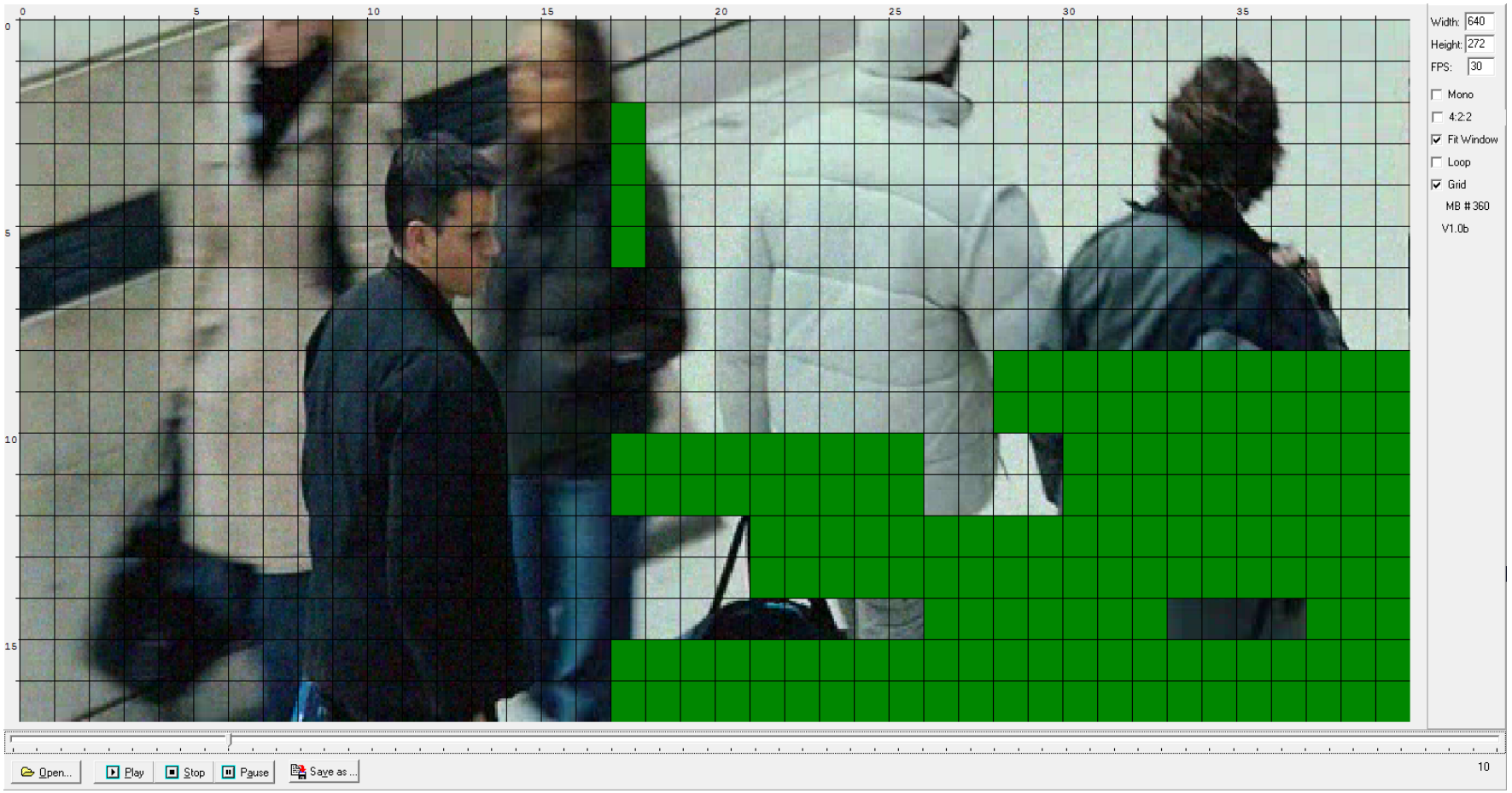


Impact of Network Errors

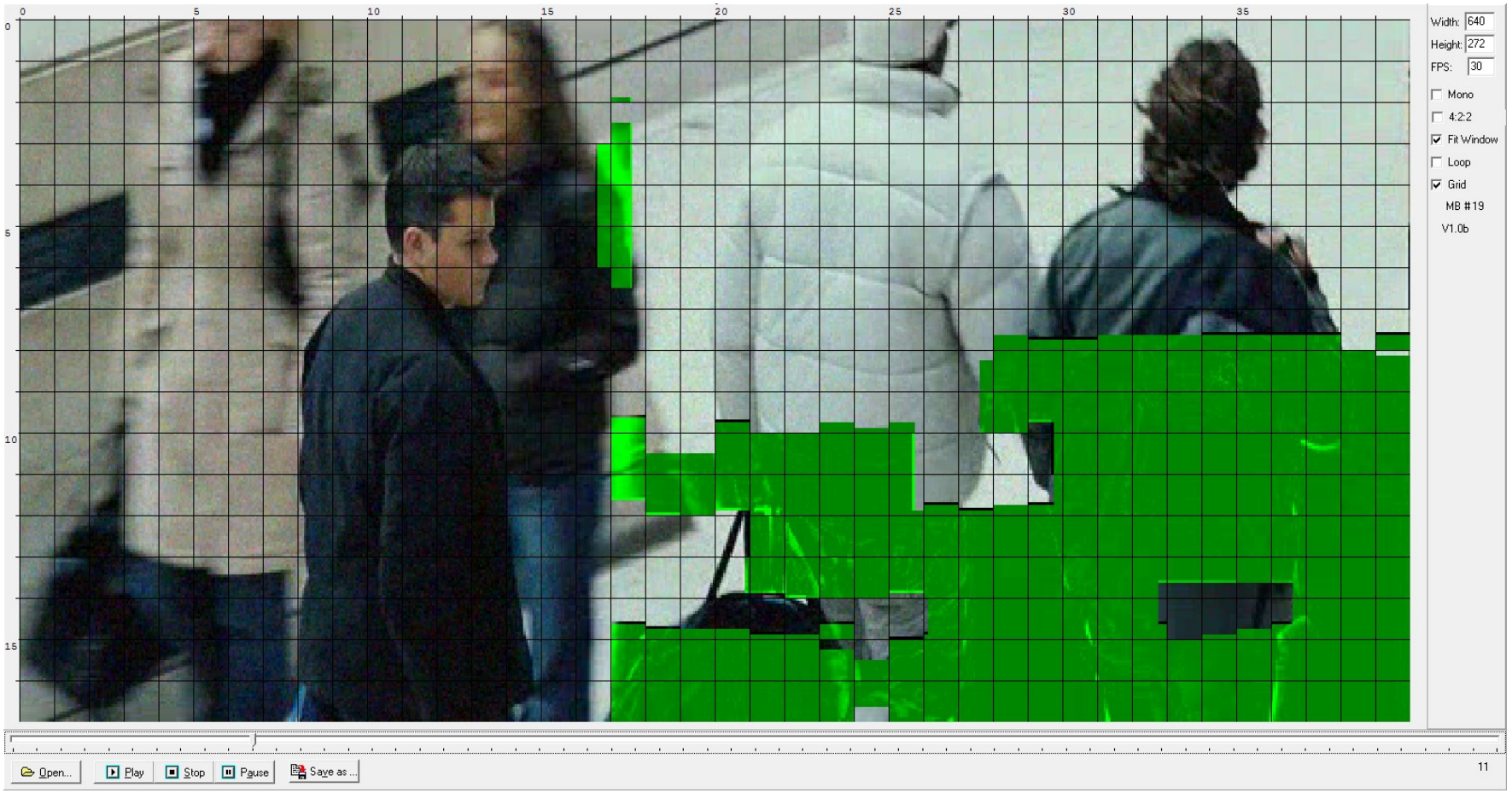
- Video compression
  - removes redundancy
    - makes transport feasible over IP networks
  - small network errors can have severe consequences
    - syntax may no longer conform to the standard used
    - spatial and temporal error propagation



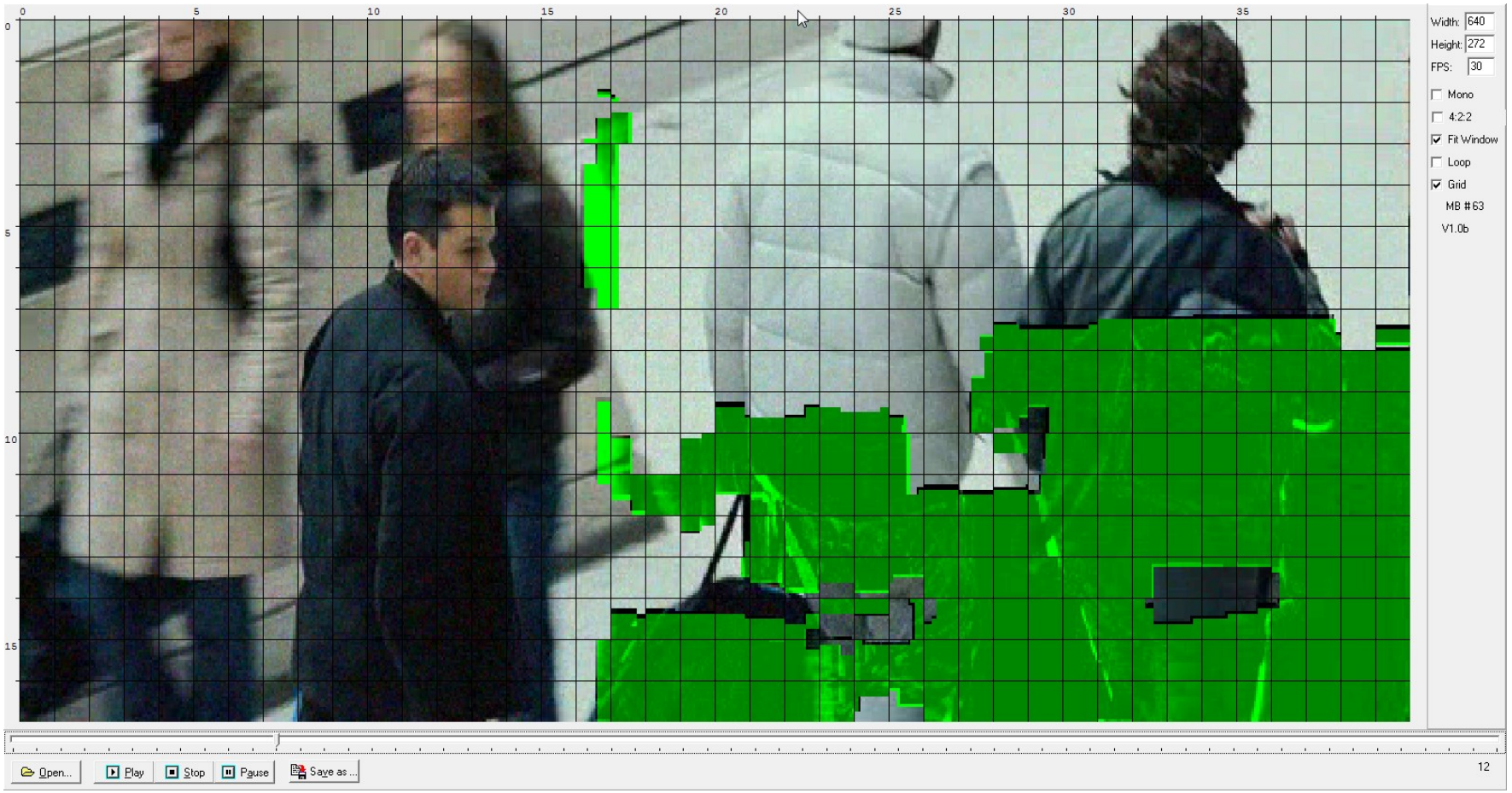
Example Impact of Packet Loss (1/8)



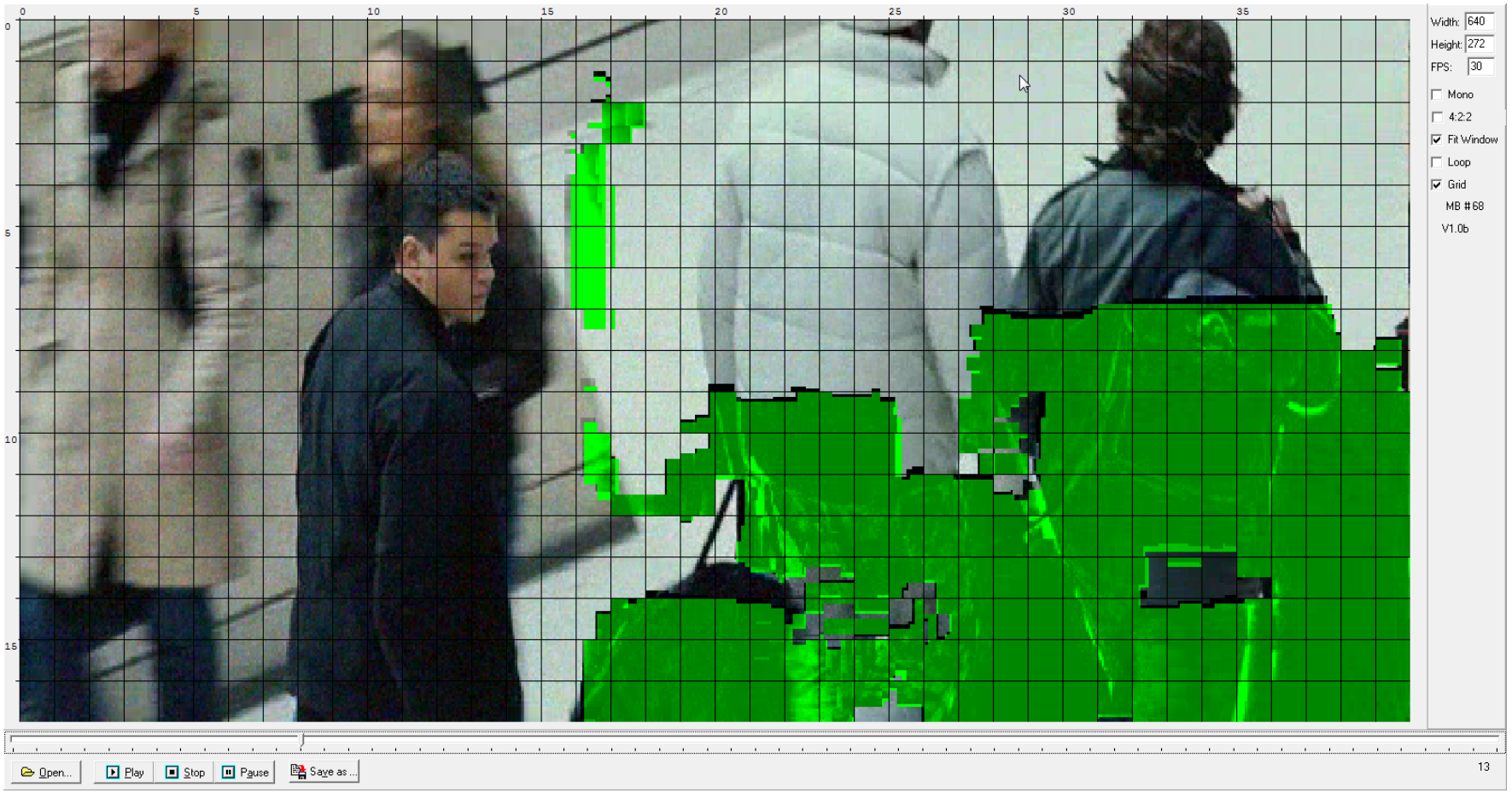
Example Impact of Packet Loss (2/8)



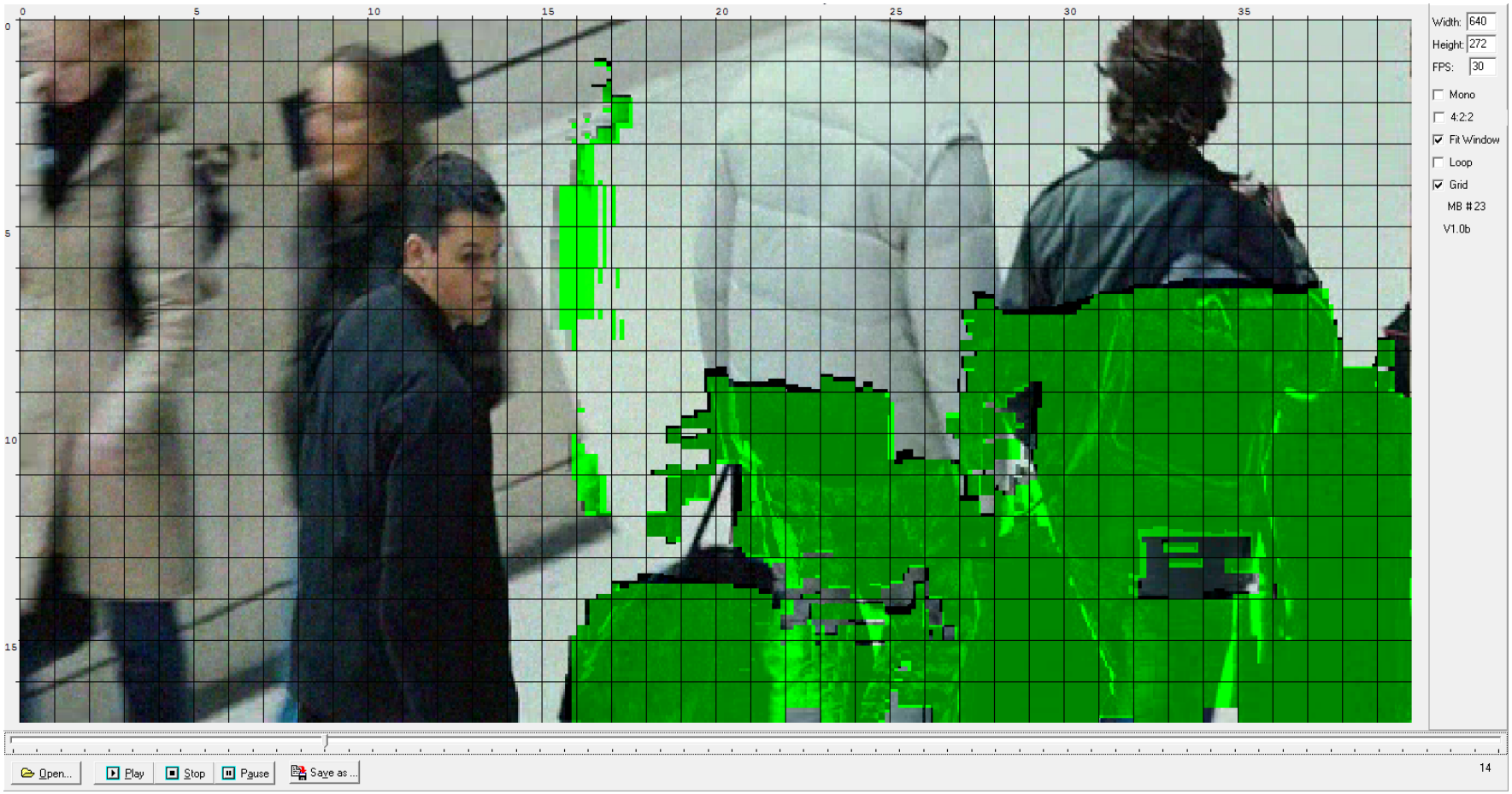
Example Impact of Packet Loss (3/8)



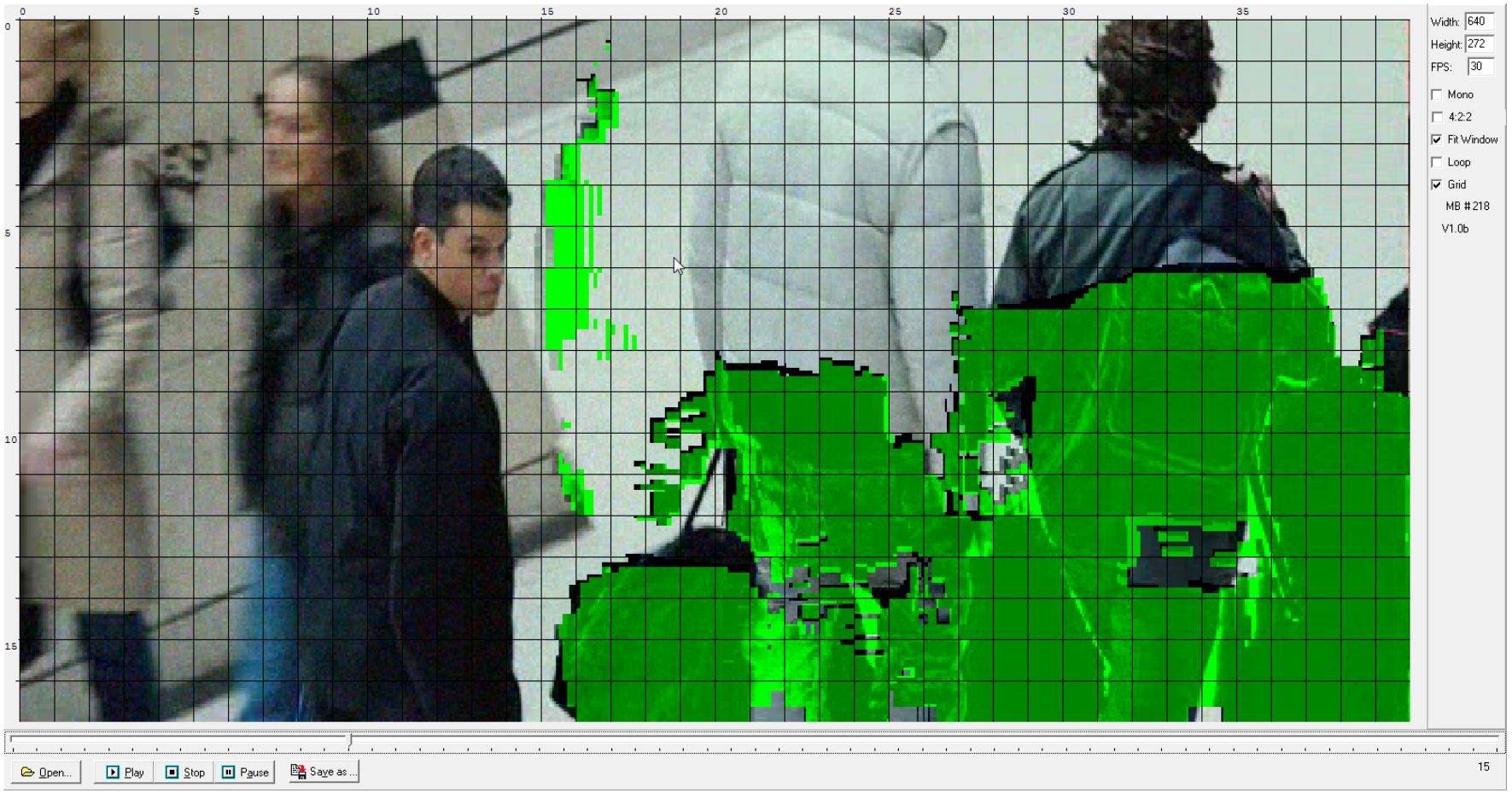
Example Impact of Packet Loss (4/8)



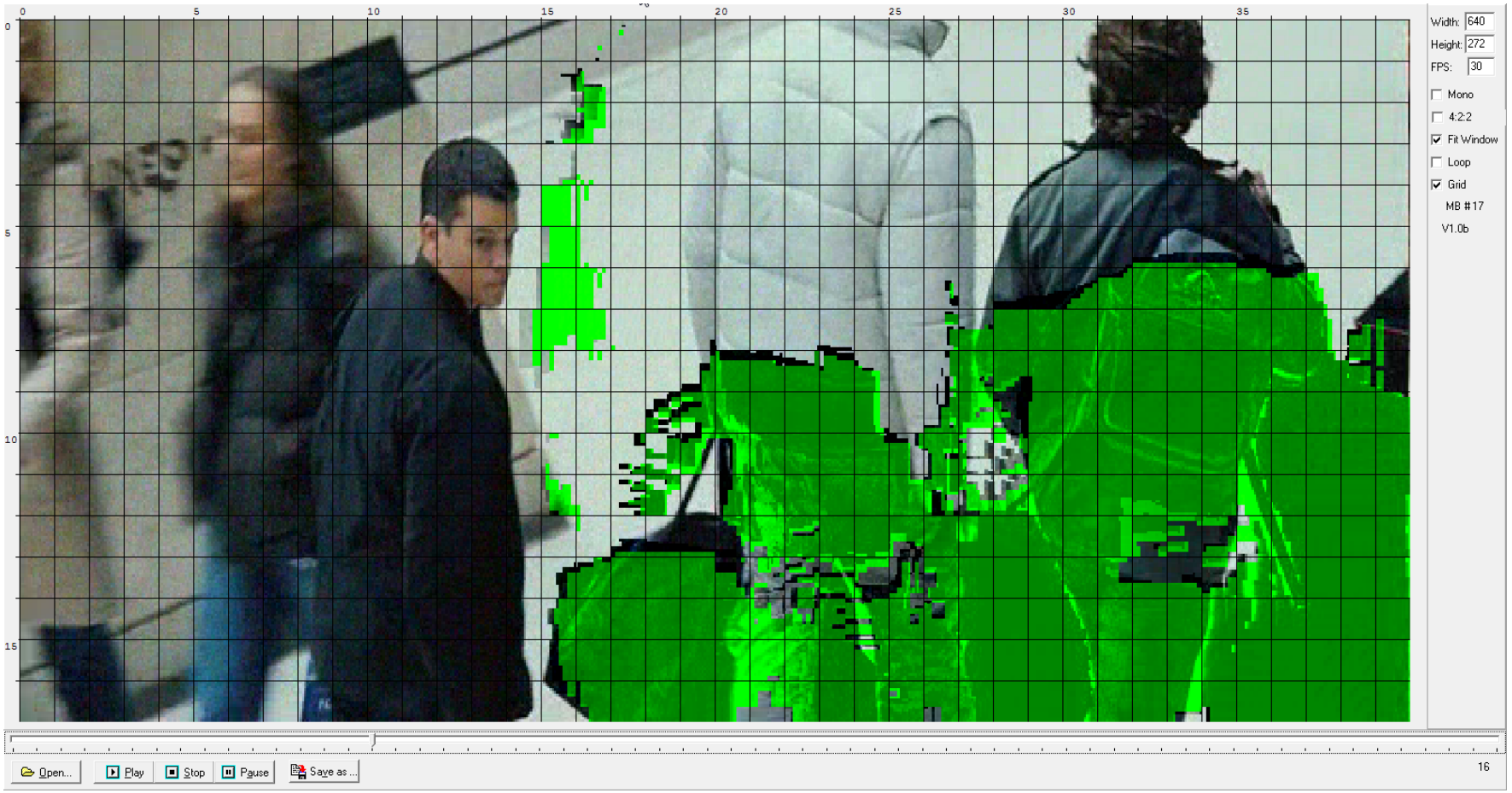
Example Impact of Packet Loss (5/8)



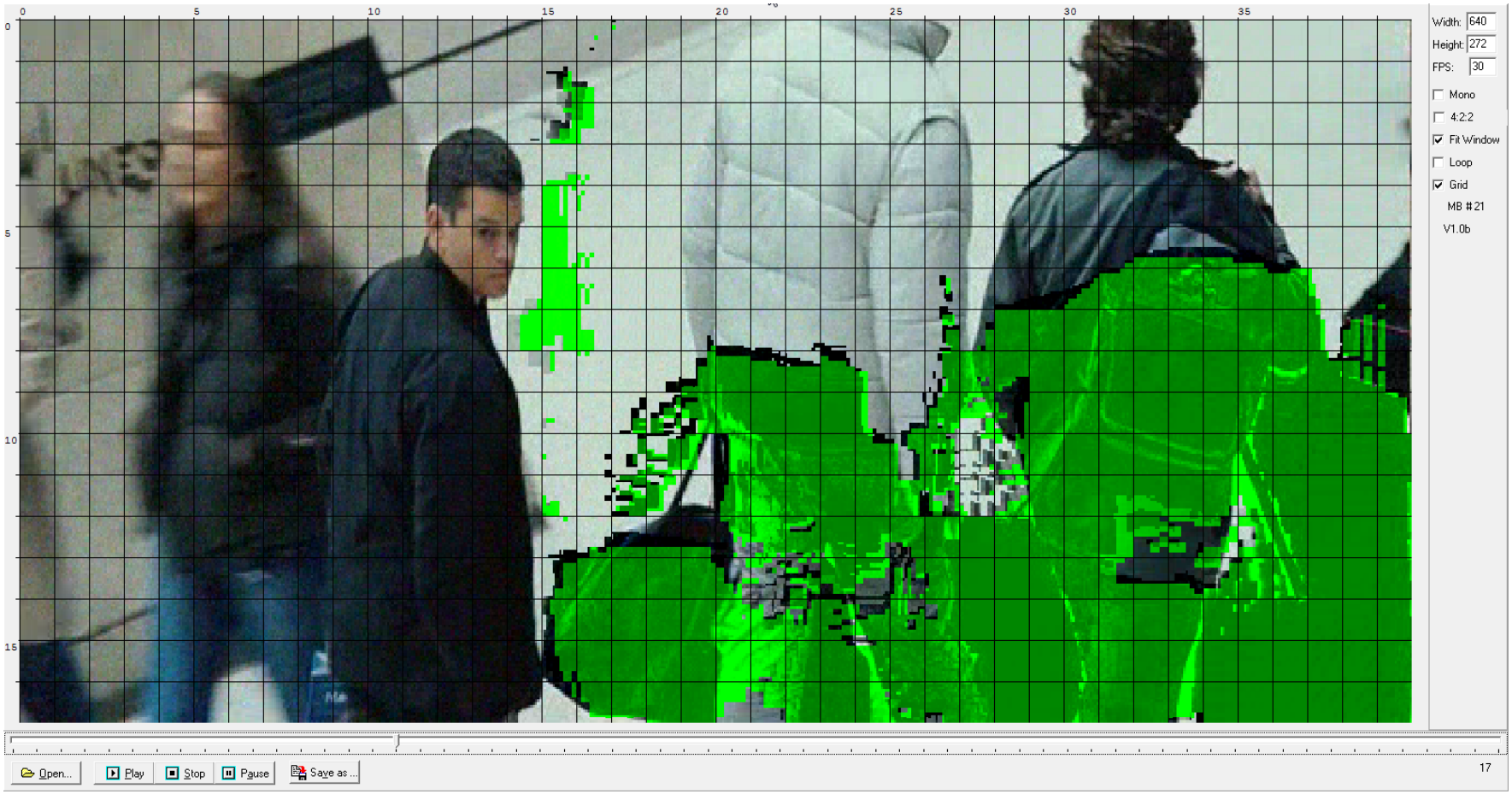
Example Impact of Packet Loss (6/8)



Example Impact of Packet Loss (7/8)



Example Impact of Packet Loss (8/8)



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- Passive error concealment
  - spatial error concealment
  - temporal error concealment
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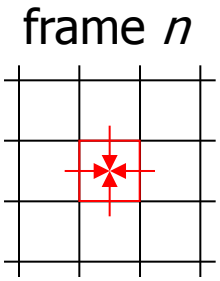
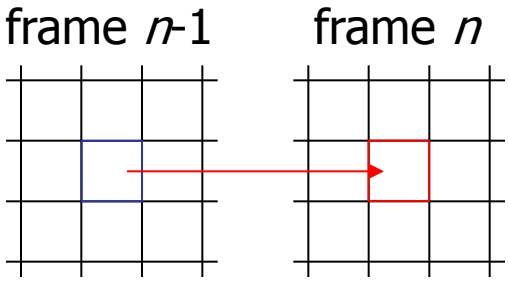
Error Concealment and Resilience (1/3)

- PASSIVE: error concealment
  - decoder
  - reconstruction of lost information
  - spatial
  - temporal





  - spatio-temporal

Error Concealment and Resilience (2/3)

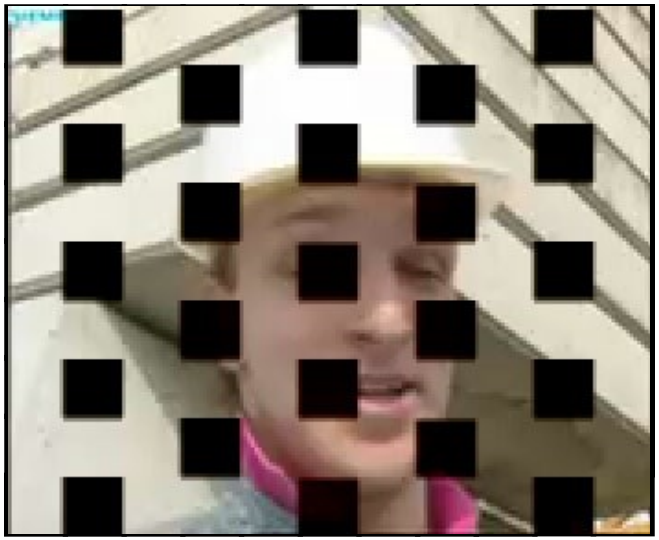
- ACTIVE: error resilience = error robustness
  - encoder
  - special techniques are used to
    - prevent errors
    - minimize the impact of errors
    - simplify the concealment of errors
  - disadvantage
    - increased bit rate

Example of Active Error Resilience

- Flexible Macroblock Ordering (FMO)
  - coding tool in H.264/AVC
  - macroblock coding/transmission 'in alternative order'
  - errors can be dealt with more effectively

without FMO

with FMO

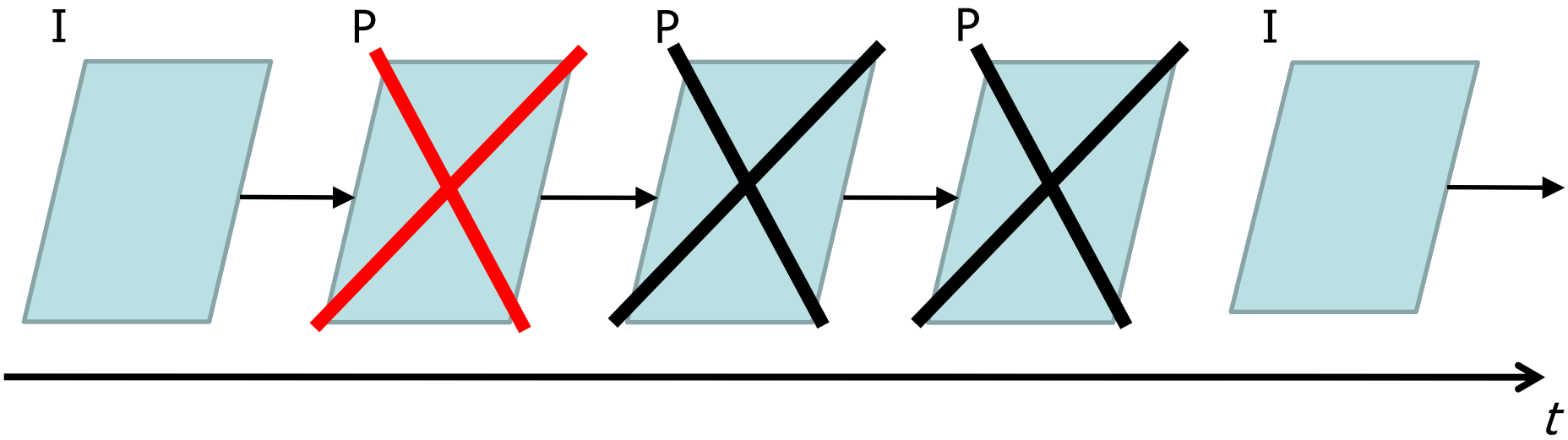


Error Concealment and Resilience(3/3)

- INTERACTIVE
  - encoder + decoder
  - feedback channel
    - decoder transmits information to the encoder
  - retransmission
    - disadvantage
      - introduces delay!

Example Interactive Error Resilience

- Retransmission of lost/corrupted frames



To avoid error propagation to the second and third P frame, the decoder can ask the encoder to resend the first P frame

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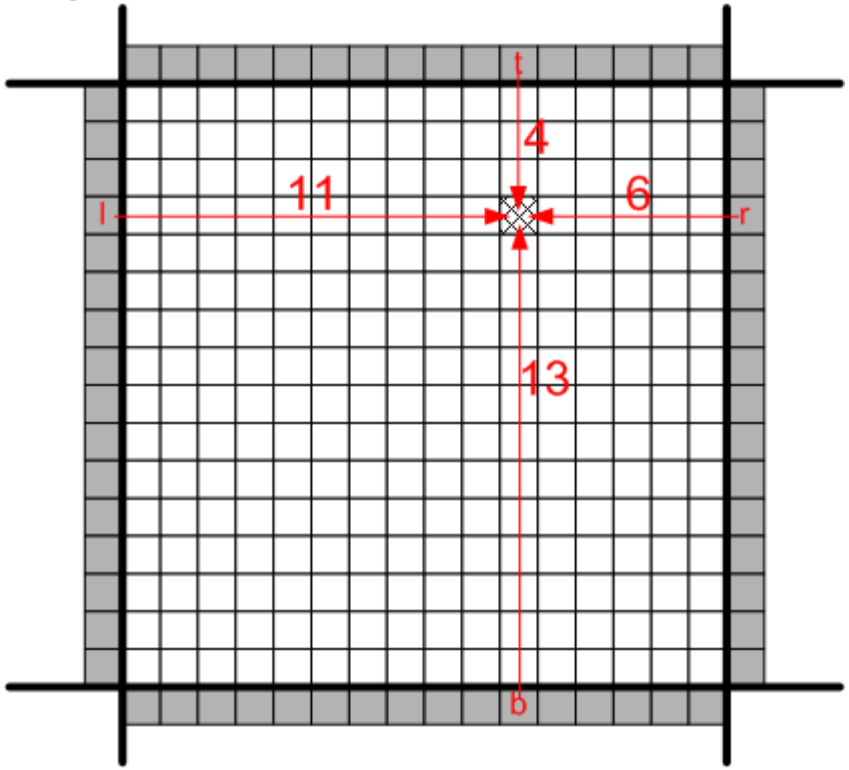
Spatial Error Concealment (1/3)

- Spatial error concealment
  - uses information from the macroblocks surrounding the macroblock lost
  - condition
    - the surrounding macroblocks have to be available
      - cf. FMO
    - or the content of the surrounding macroblocks has to be reconstructed first

Spatial Error Concealment(2/3)

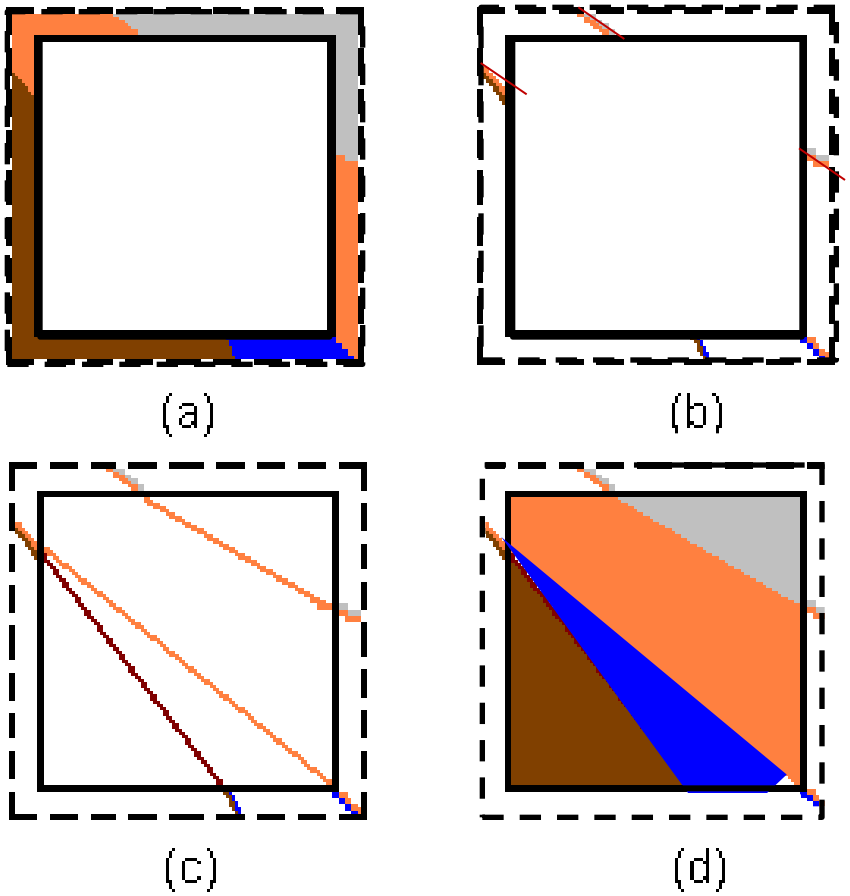
- Spatial interpolation



$$\frac{(17-11)\,l + (17-6)\,r + (17-4)\,t + (17-13)\,b}{(17-11) + (17-6) + (17-4) + (17-13)}$$

Spatial Error Concealment (3/3)

- Edge detection and edge prediction

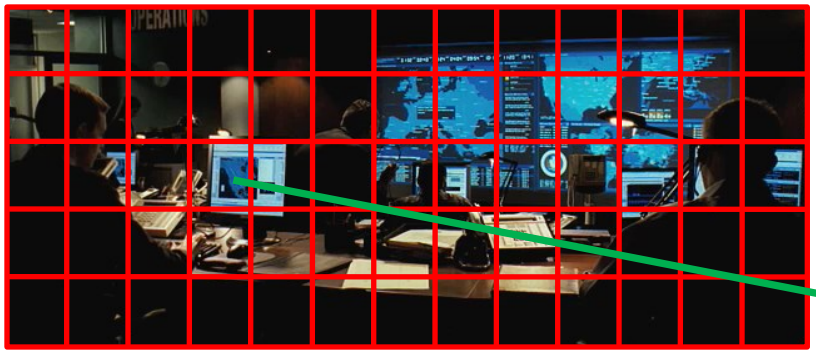


Temporal Error Concealment

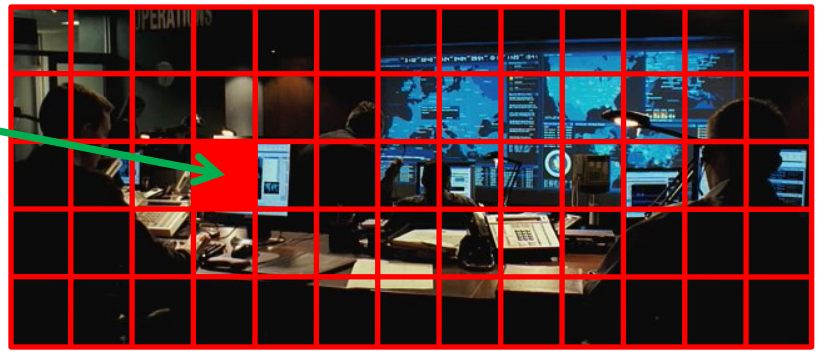
- Temporal error concealment
  - uses information from previous/following images
    - these images have to be available
    - or have to be reconstructed first
  - without motion vector
    - zero motion temporal error concealment
  - with motion vector
    - usually lost together with the residual data
    - search for the most appropriate motion vector

Zero motion temporal error concealment

- Approach
  - without motion vector
  - copy of macroblock at the same location in the previous frame (co-located macroblock)
  - works well for static objects or backgrounds



frame n-1



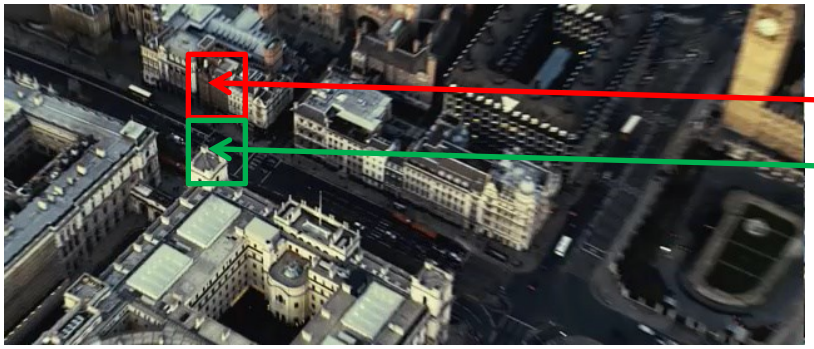
frame n

Temporal Error Concealment via Boundary Matching (1/3)

- Approach
  - with motion vector
    - use motion vector of one of the four neighbors
  - how to determine the best match?
    - resemblance between the content of the motion-compensated block and the edges of surrounding blocks

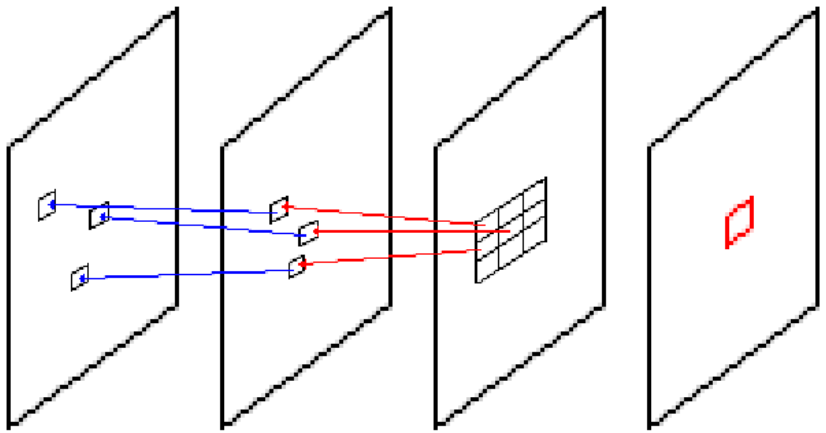
Temporal Error Concealment via Boundary Matching (2/3)

- Boundary matching



Temporal Error Concealment via Boundary Matching (3/3)

- Extending the candidate set
  - motion vectors of surrounding blocks
    - median
    - average
  - motion vectors present in previous frames
    - corresponding block previous frame
    - several frames (trajectories)



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Video Quality Measurement (1/2)

original

packet loss

- Subjective quality assessments
  - most representative but time consuming and expensive

Video Quality Measurement (2/2)

- Objective quality assessments
  - estimate the perceived video quality in an automatic way, through the use of algorithms (metrics)
    - computed estimate should correspond with the results of subjective testing
  - goal of VQEG
    - Video Quality Experts Group of the ITU
      - International Telecommunication Union
  - Easiest solution: PSNR and SSIM

Objective Quality Measurement (1/2)

- PSNR
  - Peak Signal-to-Noise Ratio
  - widely used objective quality metric (full-reference)
  - relation between
    - maximum signal ($2^n - 1 = 255$)
    - Mean Squared Error (MSE)
  - logarithmic scale

$$PSNR(dB) = 10 \log_{10} \frac{(2^n - 1)^2}{MSE}$$

$$MSE = \frac{1}{N * M} \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} \left(f(x,y) - f'(x,y)\right)^2$$

Objective Quality Measurement (2/2)

- SSIM
  - Structural Simularity Metric
  - Gains interest in the academic world (full-reference)
  - Evaluates the average, variance, and co-variance between pixels for the original and reconstructed
  - Takes into account the perceived quality

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Test Environment

- Given
  - encoder (executable)
  - decoder (source code in C/C++)
    - can simulate transport errors
      - ErrorSimulator
    - can correct transport errors
      - ErrorConcealer
  - tool for calculating PSNR and SSIM (executable)
  - YUV viewer (executable)
  - uncompressed video sequences
  - error patterns (simple / complex)

Error Simulation

- Simulation of transport errors
  - in the encoded bitstream
    - damaged bitstream is not conform to the syntax
    - complex decoder is required to handle this
  - in the decoder
    1. decodes full frame (without loss)
    2. simulates transport errors
       - deletes information for certain macroblocks
    3. corrects simulated transport errors
    4. saves the corrected frame
       - used as a reference for decoding of the next inter-coded frame

Outline Exercises (1/3)

- Exercise 1: creation of the test sequences
  - encoding of bitstreams

- Exercise 2: spatial error concealment
  - Exercise 2.A
    - simple spatial interpolation
    - neighboring macroblocks are available
  - Exercise 2.B
    - general spatial interpolation
    - connected macroblocks can be lost
  - Exercise 2.C
    - use of edge information (challenge!)

Outline Exercises (2/3)

- Exercise 3: temporal error concealment
  - Exercise 3.A
    - zero motion temporal reconstruction
  - Exercise 3.B
    - reconstruction by means of simple boundary matching
    - neighboring macroblocks are available
  - Exercise 3.C
    - reconstruction by means of general boundary matching
    - connected macroblocks can be lost
    - pay attention to content adaptivity (challenge!)

Outline Exercises (3/3)

- Exercise 4: evaluation and report
  - quality and time complexity measurements
  - write a report (in English)
    - clear explanation of algorithms implemented
    - evaluation of the algorithms implemented
    - answer the given questions
  - important!
    - report has to be clear and well-structured
      - choose the best way to visualize your results
    - length of the report
      - absolute maximum: 6 pages
      - quality above quantity!

Assignment (1/2)

- Deadlines
  - Exercises 1, 2, and 3
    - October 23rd, 16h00 (Thursday)
  - Exercise 4
    - October 30th, 16h00 (Thursday)

- Recommendations
  - solve the exercises in the right order
  - when sending an email, use [DMA] to start the subject line

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Assignment (2/2)

- Groups
  - three people
  - mixed!
    - maximize diversity regarding your academic background (*i.e.*, your bachelor: EBCOMP / CBINFO / ING)
    - will be checked upon registration
  - deadline for group registration
    - October 6th, 16h00 (Monday)