Watermarking: Applications and Current State of the Art

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Outline

- Introduction
- Applications
- Requirements
- Data Hiding Approaches
- Future Directions and Conclusion

Data Embedding

- Content description & management
  - IPR data: originator, creation parameters, version control, editing
- Rights management and protection
  - audit trail, monitoring, copy/no copy control, linking to a player
- Fraud detection
- E-commerce
  - hyperlink to sales site
- Customized/Enhanced media delivery
  - customized commercials
  - customized viewing

Embedded Info (e.g., text, audio, video, etc.)

Perceptually Unchanged

Watermark Detector

Embedded Info

Application

Rights Management and Protection

SDMI World

-Compliant Devices/Players
-Secure Media
-Rippers
-DRM rules- Copy/No Copy

SDMI attempts to:

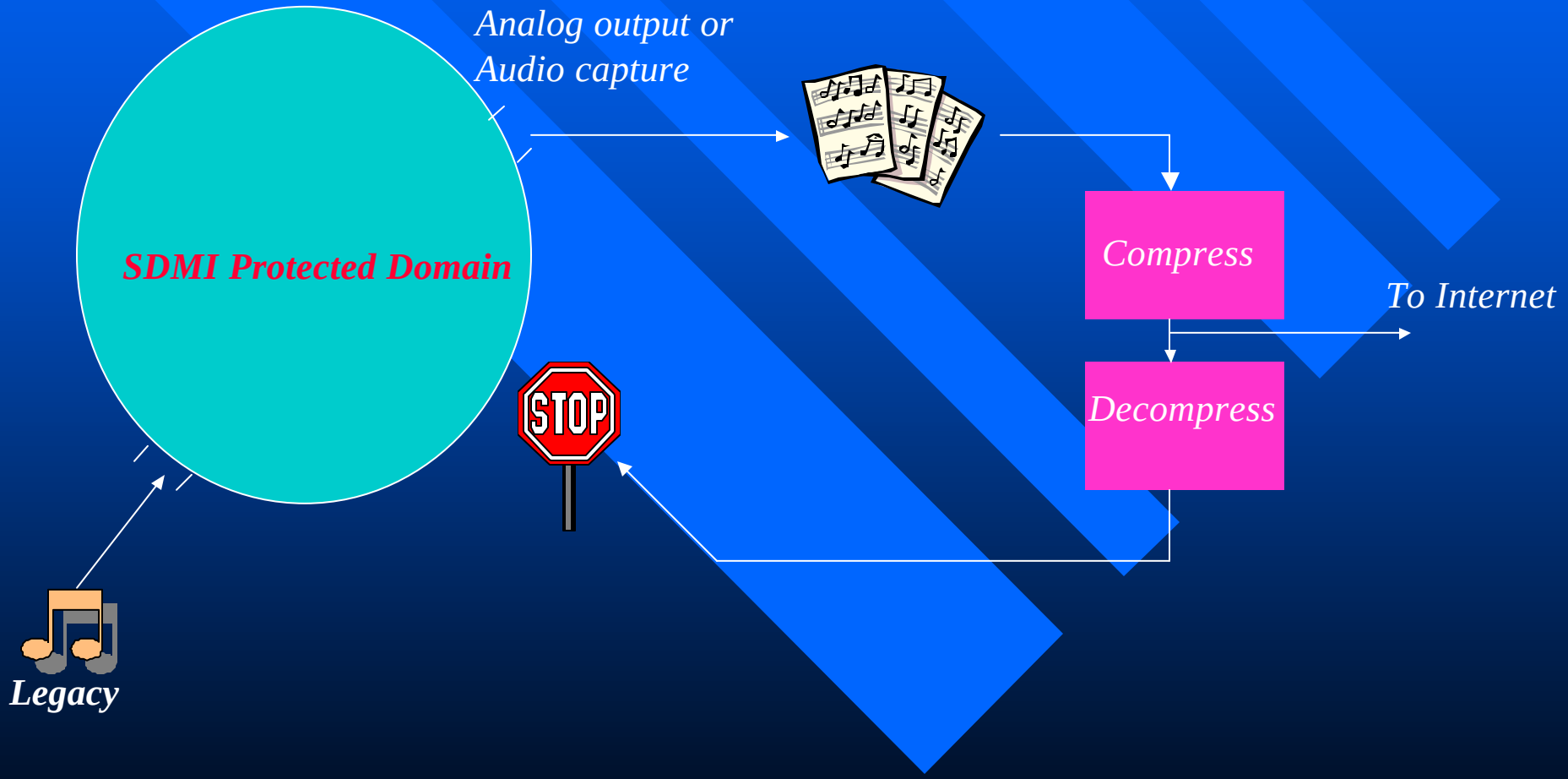
- Create an environment for legitimate distribution of music

- Eliminate illegal download and swapping of copyrighted music

SDMI: Secure Digital Music Initiative – Consortium of 200+ technology companies

Application

Rights Management and Protection



Application

Rights Management and Protection

- Robust Watermark
  - Copy Control/Source Information
  - Fragile watermark assertion
- Fragile Watermark
  - Disappearance indicates compression

SDMI Requirements

Robust Watermark

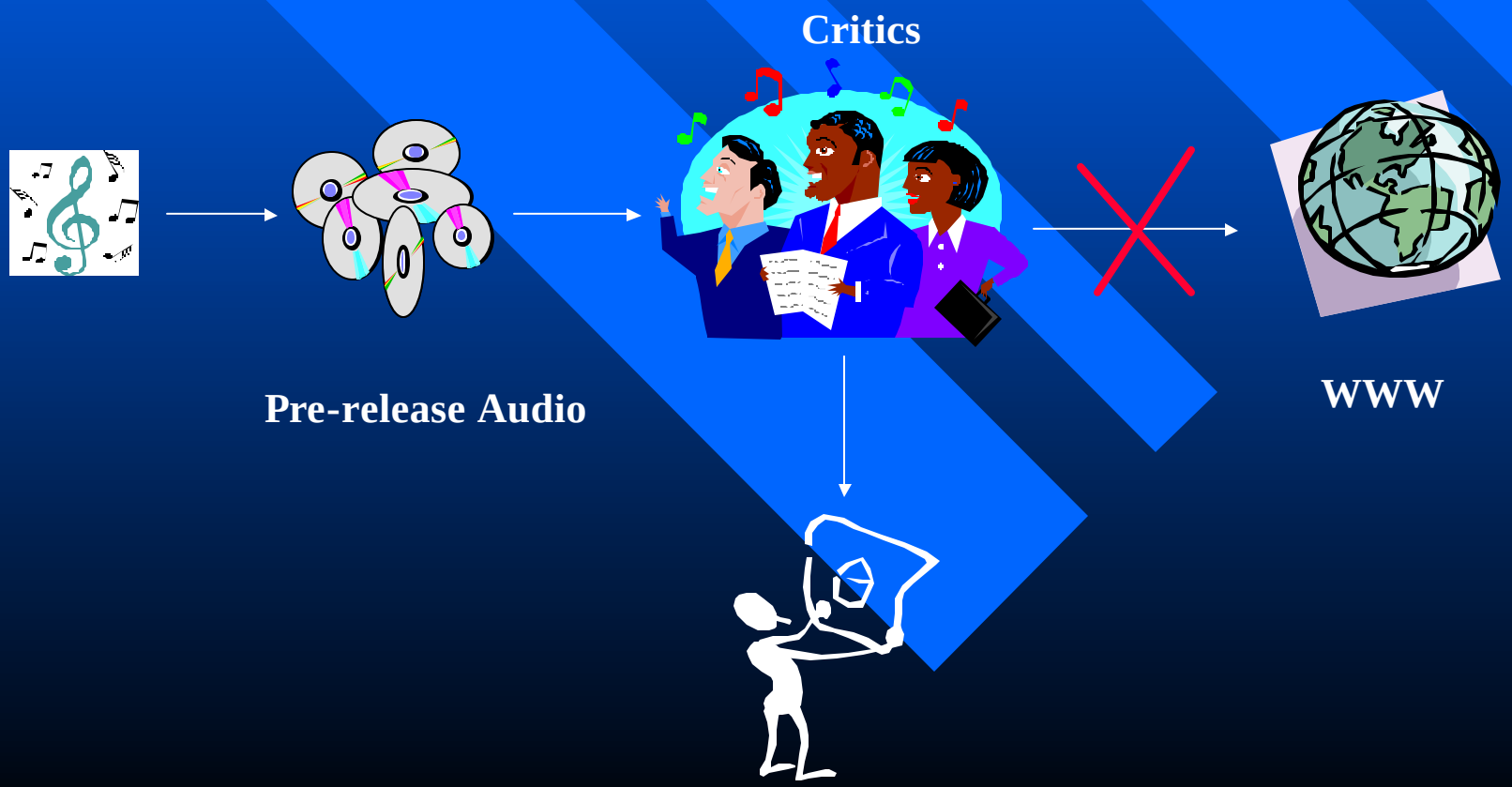
- Transparency
- Two successive D/A and A/D conversions
- Linear Speed Change of +/-10 %
- Audio coding (MPEG, AC-3,AAC, …)
- Dynamic range reduction
- Additive noise
- Down-mixing and Surround sound processing
- Echo Addition
- Bandpass filtering
- Low complexity

Fragile Watermark

- Transparency
- Anything but coding
- Low complexity

Application

- Watermarking of Pre-release Audio

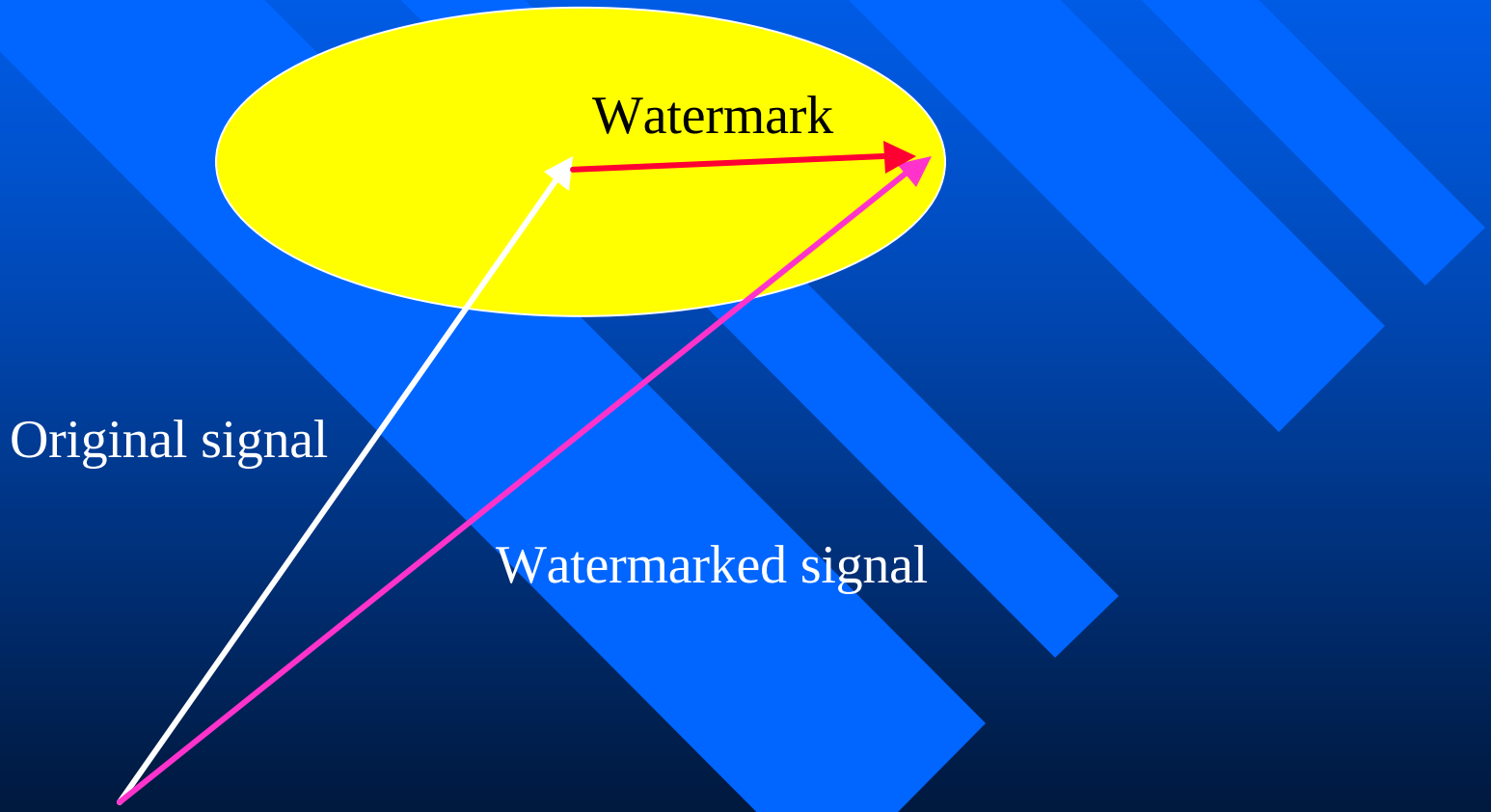


Data Embedding Issues

- Transparency
- Capacity
- Robustness
- Security

Masking and Data Embedding

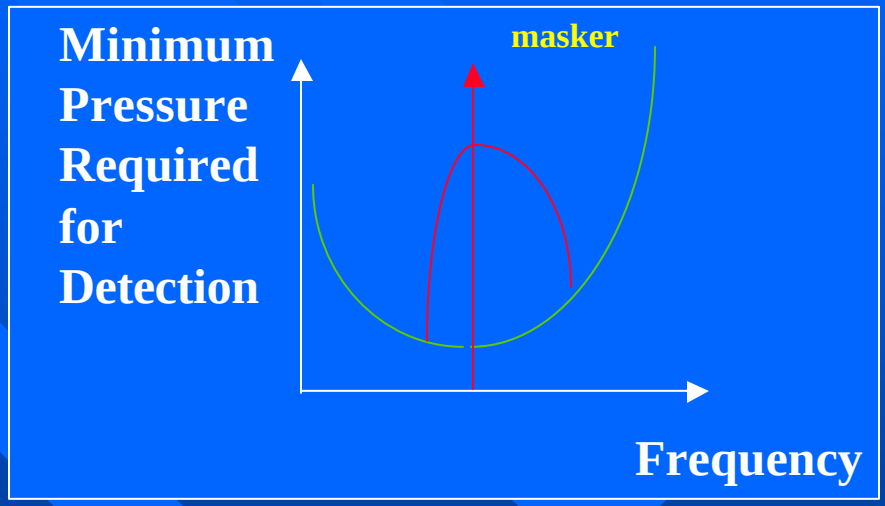
Add watermark such that watermarked signal is perceptually equivalent to original

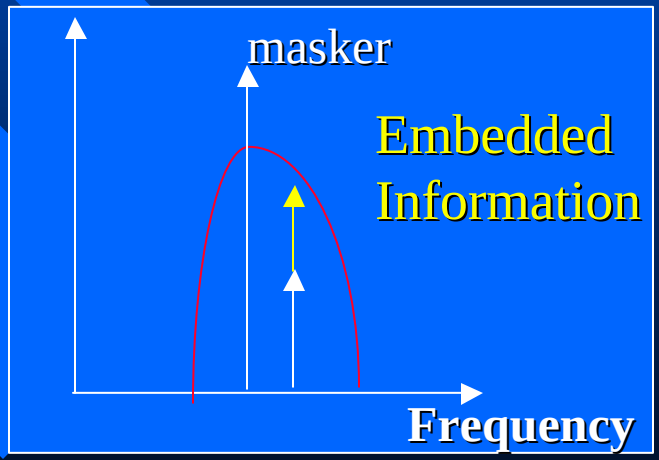


Transparency tested via blind tests

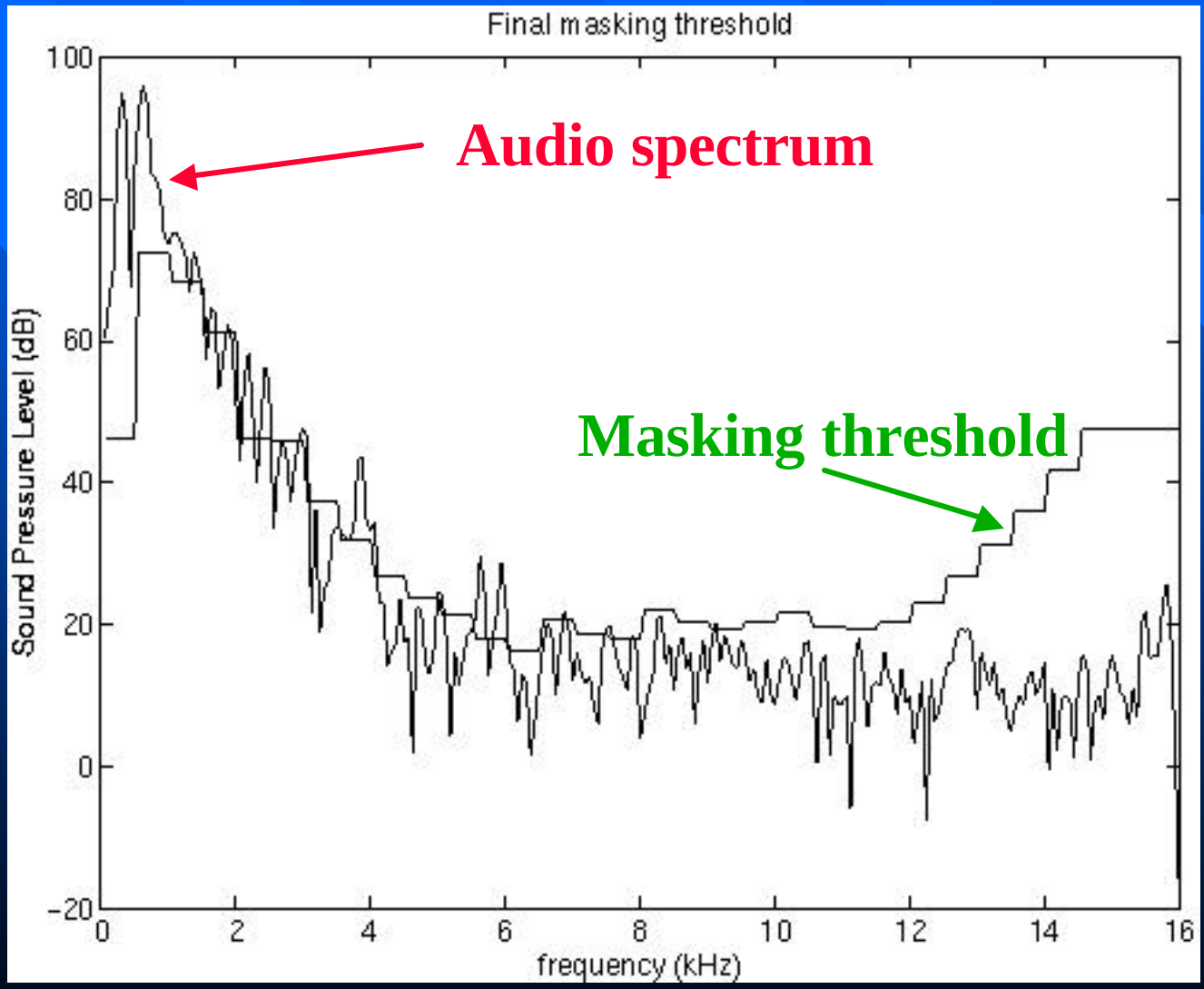
Masking

- Signal is perceptually inaudible or invisible in the presence of a masking signal
  - frequency masking
  - temporal masking
- Challenges:
  - variable embed rates
  - how to use masking at extract end?

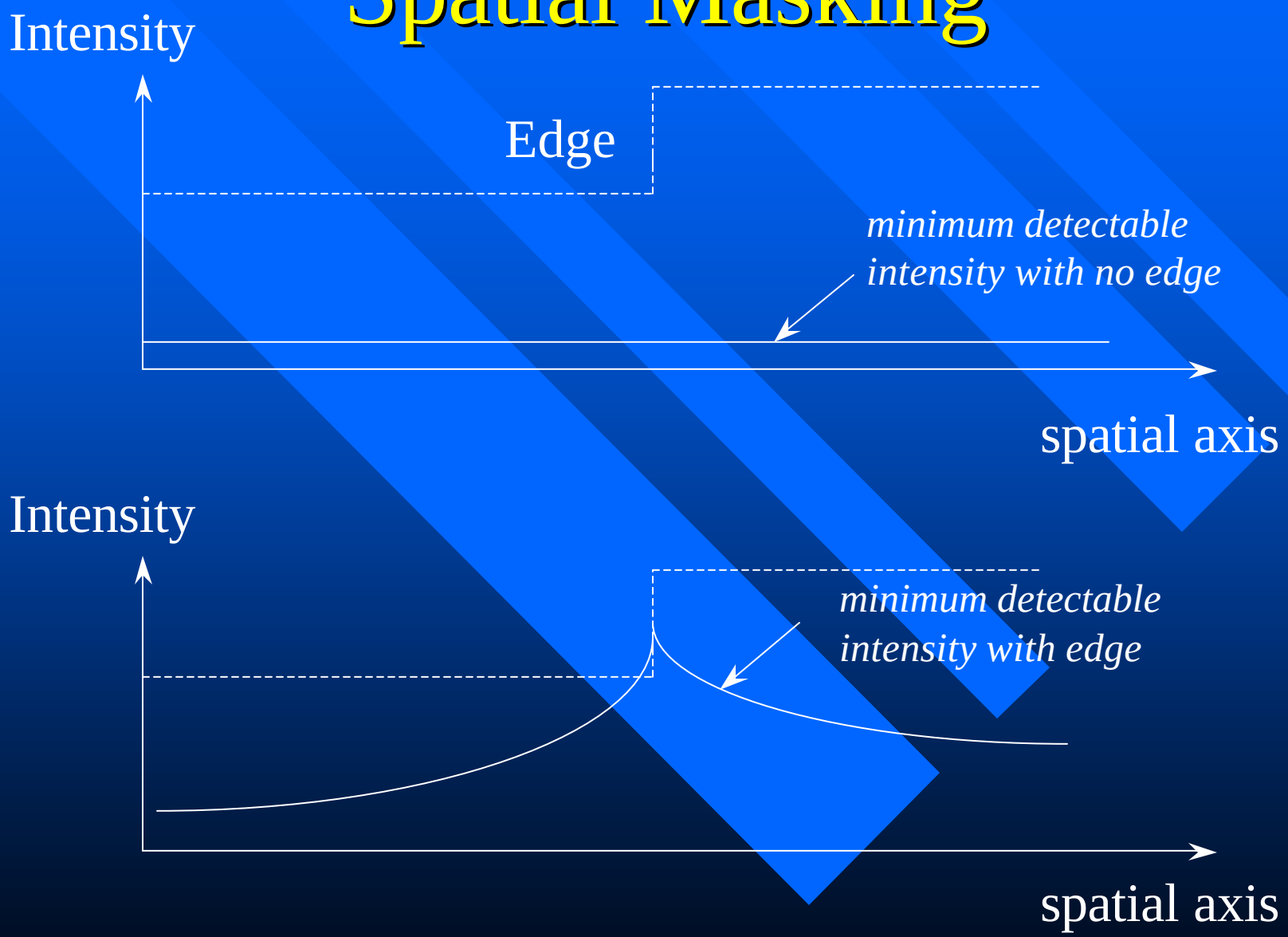




Example: Frequency masking in audio



Spatial Masking



Data Embedding Issues

- Transparency
- Capacity
- Robustness
- Security

Data Embedding Capacity

- Capacity depends on initial representation
- Capacity inversely proportional to robustness

Host Signal	Byte rate or byte density
Audio	<1 – 256 bytes/sec in mono CD quality audio signal
Image	<1 – 256 bytes in 8 bits gray scale 128x128 image
Video	900 – 9216 bytes/sec in 320x240 8 bit gray scale 24 frames/sec video

Data Embedding Issues

- Transparency
- Capacity
- Robustness
- Security

Robustness Issues

- Compression: JPEG, ZWT, etc.
- Filtering
- Additive noise
- Scaling and cropping
- Rotation
- Printing and Scanning

SDMI Requirements

Robust Watermark

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Fragile Watermark

- Transparency
- Anything but coding
- Low complexity

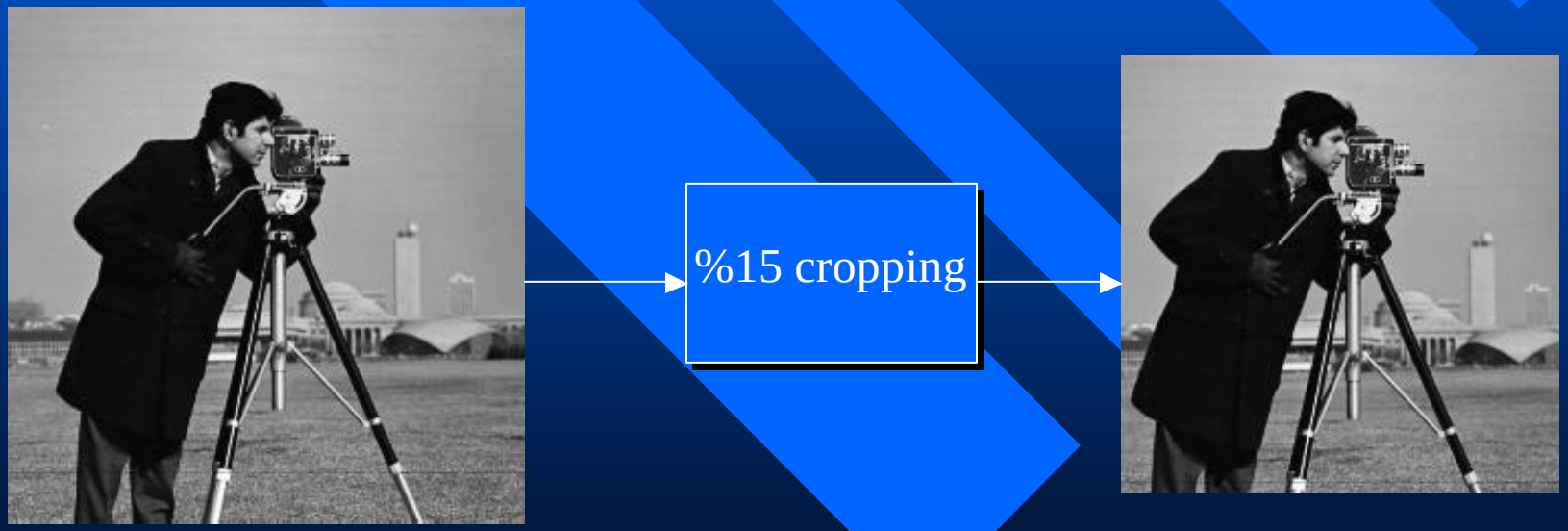
Rotation and Scaling

Original Image

Rotated two degrees and scaled

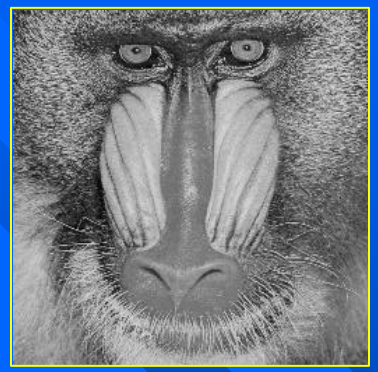
Cropping

- Only considers a small segment of the image

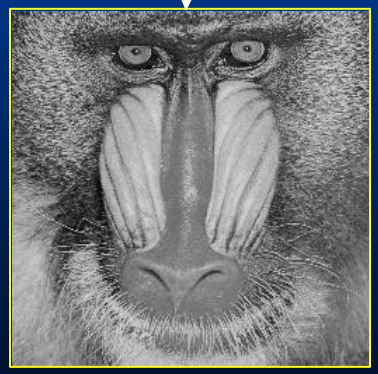


Data Embedding Techniques

- Additive schemes
- Modulation (quantization) based schemes
- Self-Synchronizing schemes



Embedded Info (e.g., text, audio, video, etc.)

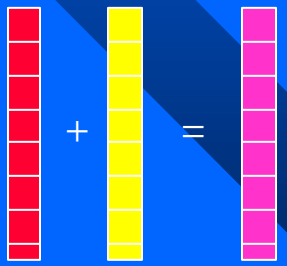


Perceptually Unchanged

Additive Techniques

Image or Audio Block

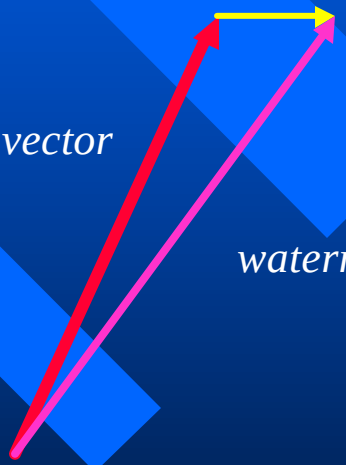
Data vector



Data vector

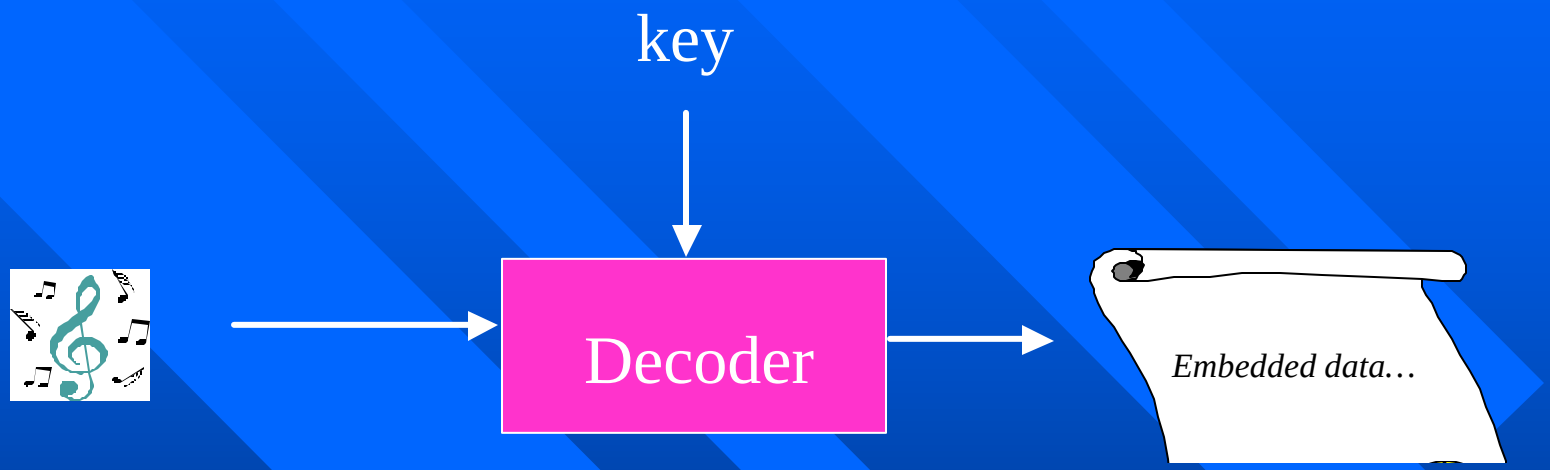
watermark vector

watermarked vector



Additive Watermarking

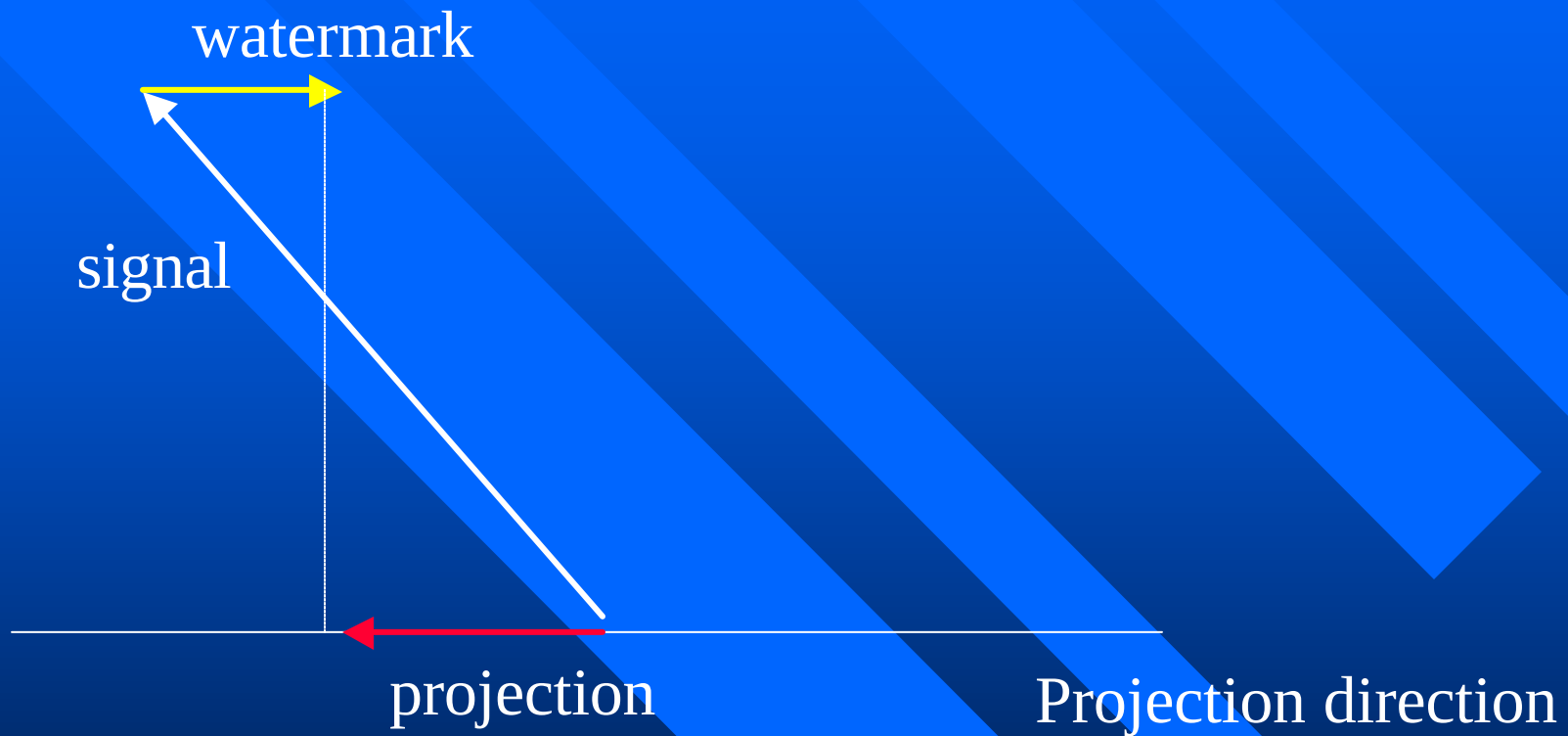
Data Extraction



Challenges:

- optimal use of masking
- dealing with host signal: major challenge for additive schemes
- dealing with distortions: synchronization problem

Additive Techniques



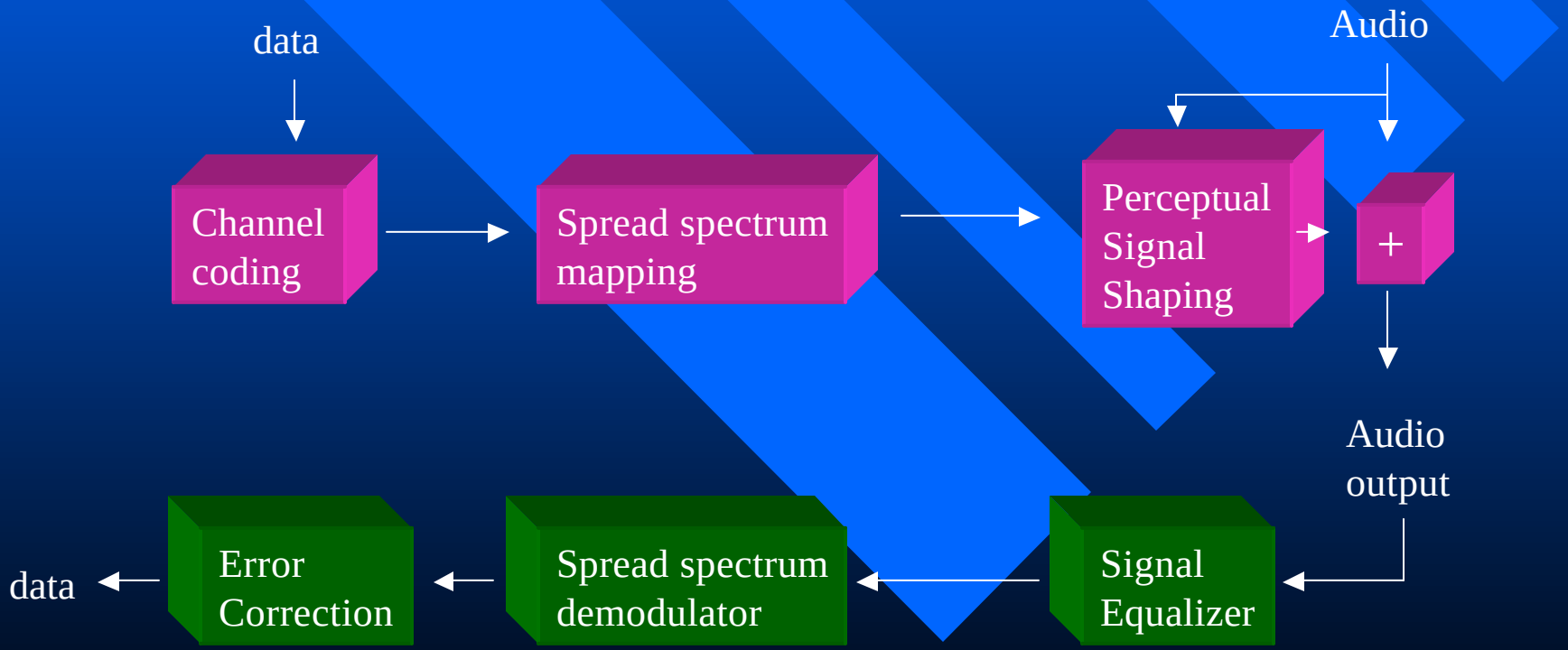
- Strong signals confuse watermark detector.
- To decorrelate signal and watermark:
  - use properly designed watermarks
  - use longer blocks

Spread-spectrum Techniques

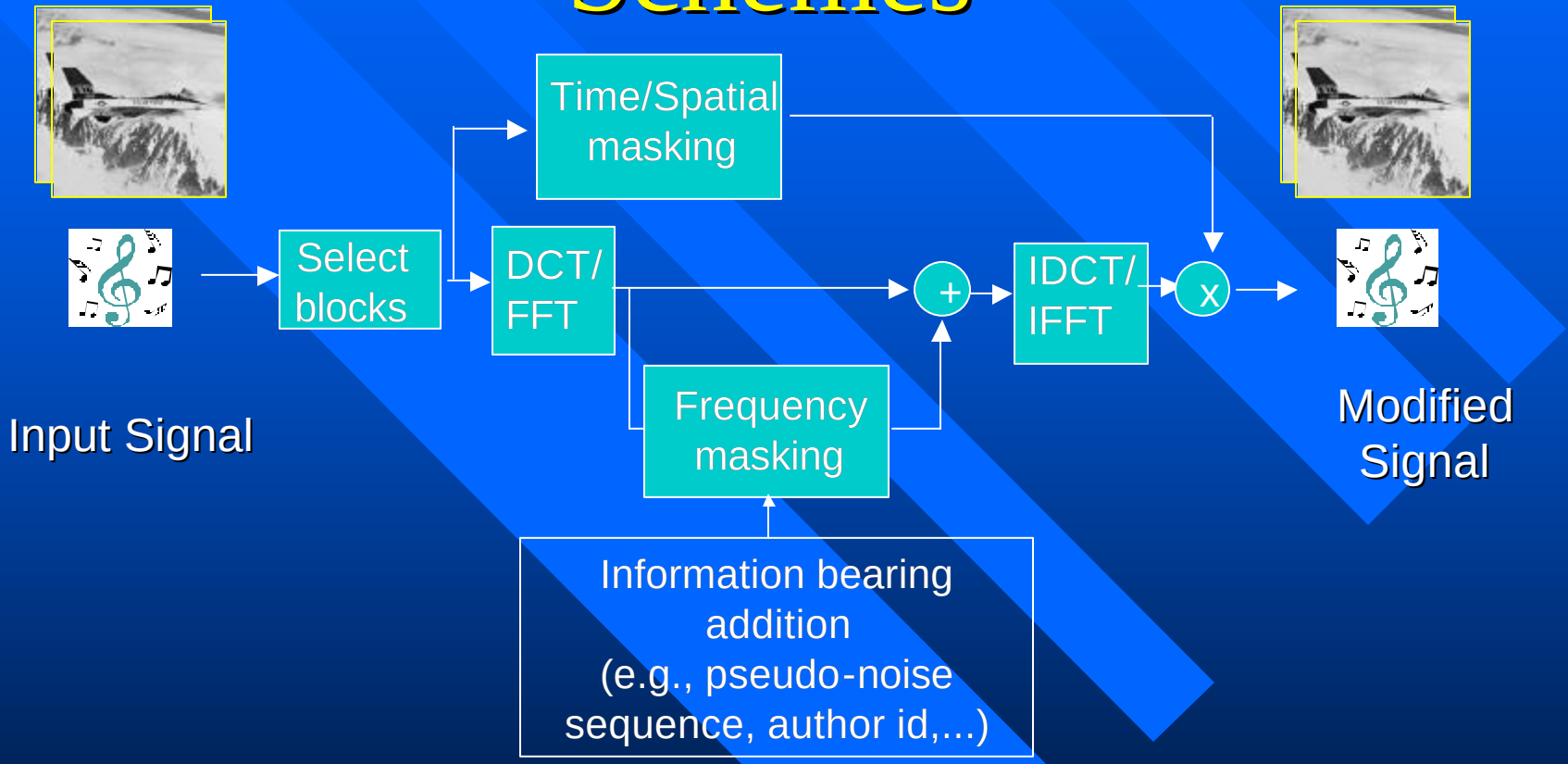
- Most popular approach
- Originated with BBN in audio domain
- Principle:
  Add noise-like sequence in frequency domain or at random frequency, time or space locations to ensure that watermark and signal are uncorrelated.

Spread-spectrum Communications

- Original BBN technique (1994 patent)



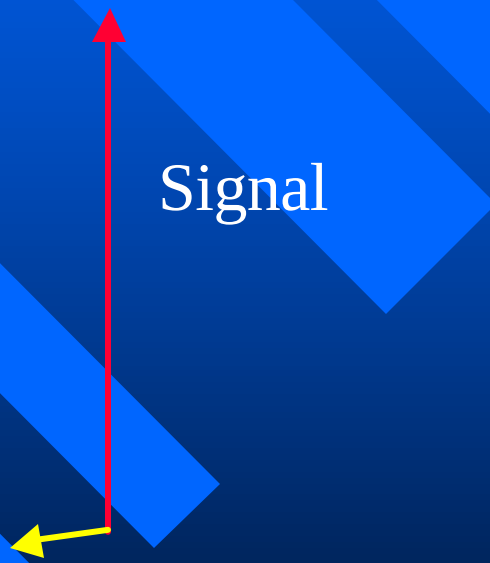
Additive Data Embedding Schemes



- Spread-spectrum approaches
- Echo coding

Spread-spectrum Communications

- Advantages:
  - secure, noise-like, undetectable
  - robust to interference/attack

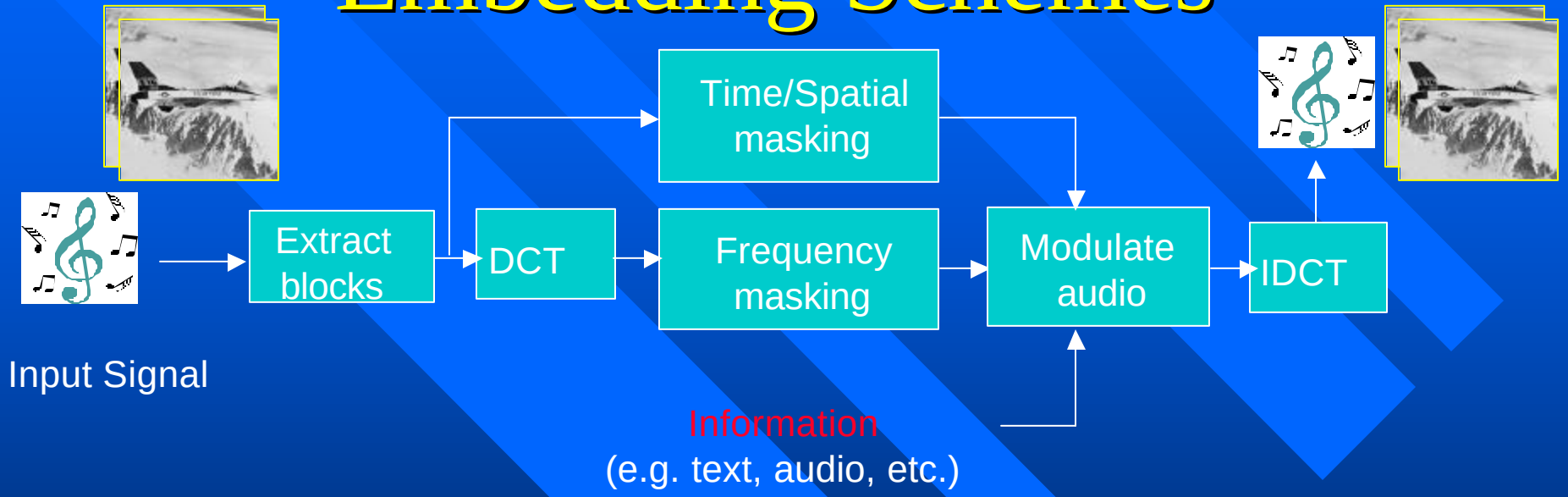


Watermark nearly orthogonal to signal

Additive Techniques

- Limitations:
  - low capacity
  - require proper synchronization
  - masking challenge

Modulation Based Data Embedding Schemes

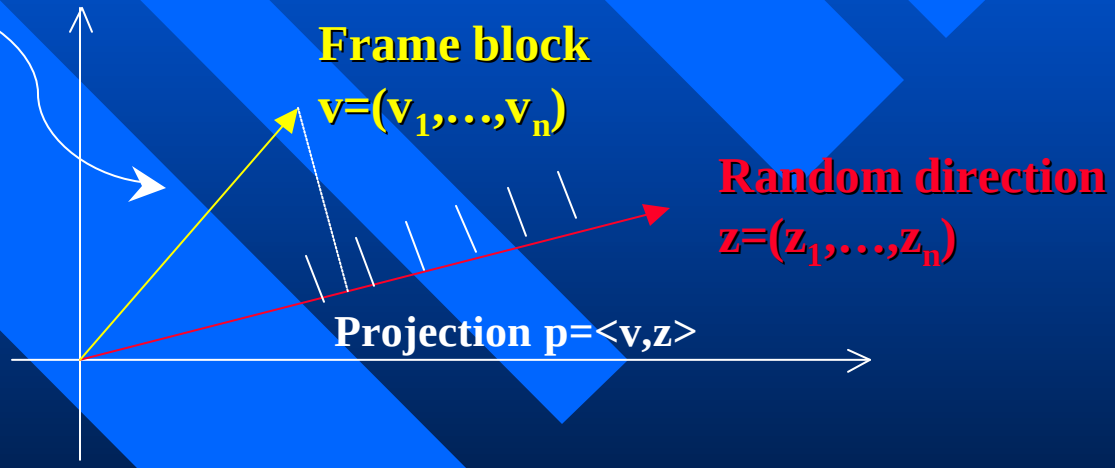


- Least significant bit modification
- Phase modulation
- Band or patch replacement
- Quantized projections

LSB Approaches

- Re-quantize coefficient values
  xxx….1x=1
  xxx…..0x=0
- Can embed 1 or more bits per sample with no distortion
- Requires error correction
- As more redundancy is added, tends to spread-spectrum approaches

Projection Approach

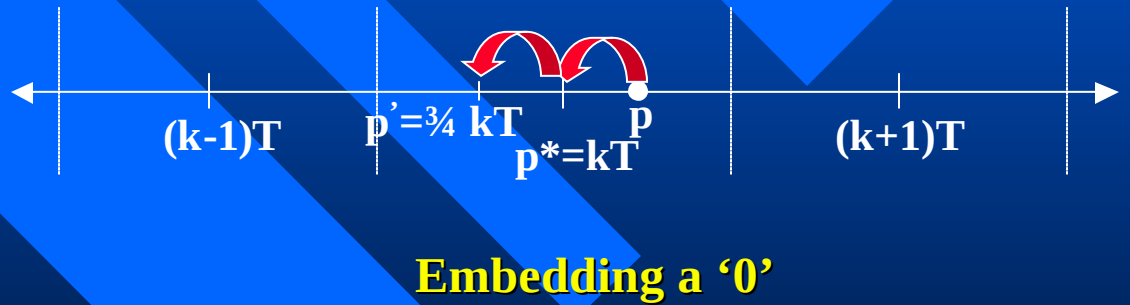


Quantization

Embedding data

projection quantized by threshold *T*

Quantized projection perturbed by +/- *T/4*



Embedding a '0'

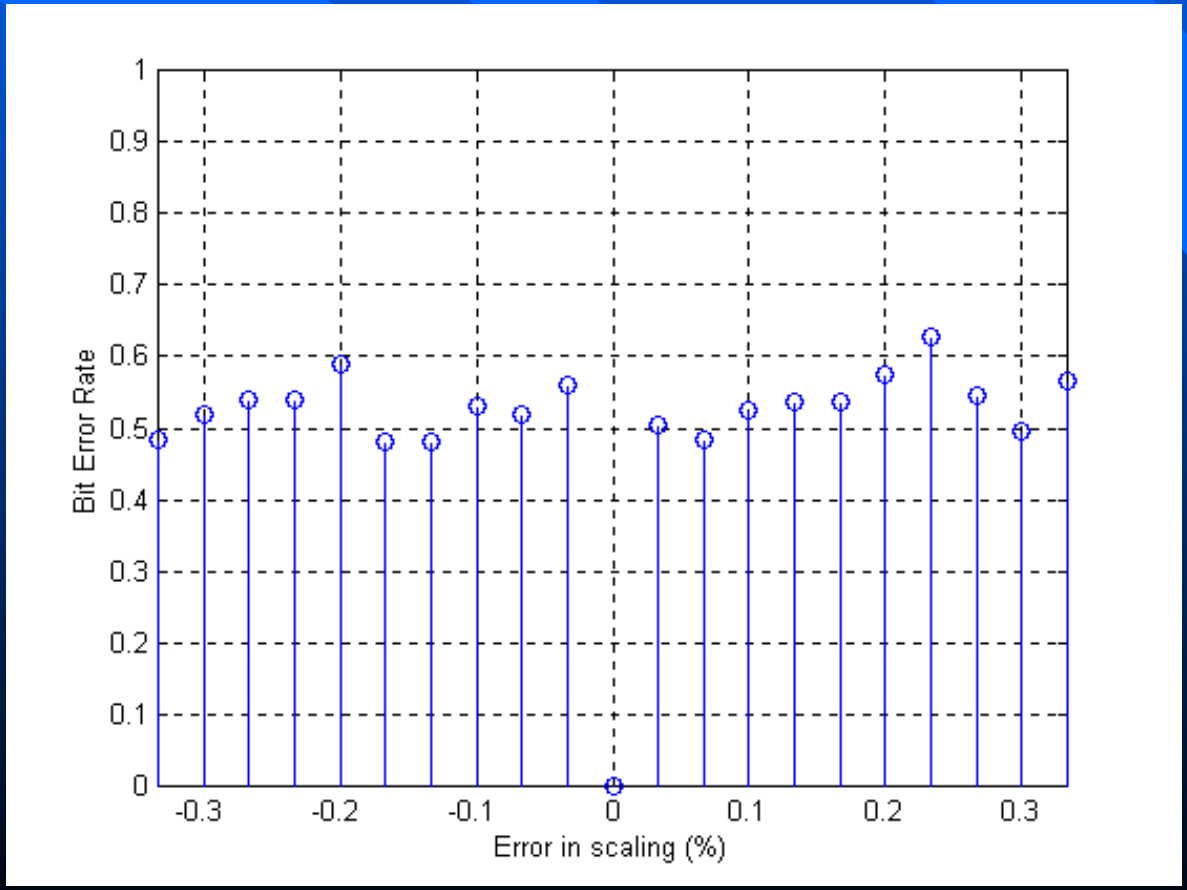
$$\vec{v}' = \vec{v} + (p' - p) \cdot \vec{z}$$

Projection Approach

- Advantages
  - large capacity
  - ease of incorporating masking
  - robustness
- Limitations
  - slow synchronization:
    - » sensitive to scaling and rotation,
    - » requires slow, exhaustive search

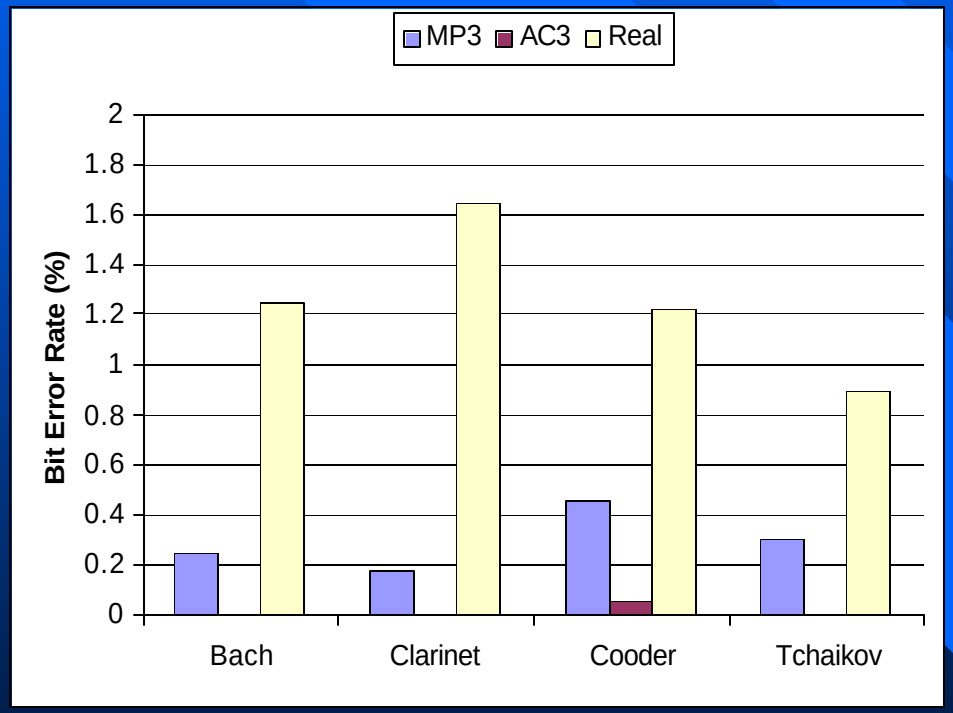
Incorrect Scale

- Bit error rate at incorrect scale. 42 blocks of length 1024, 1 bit/block, DCT quantization



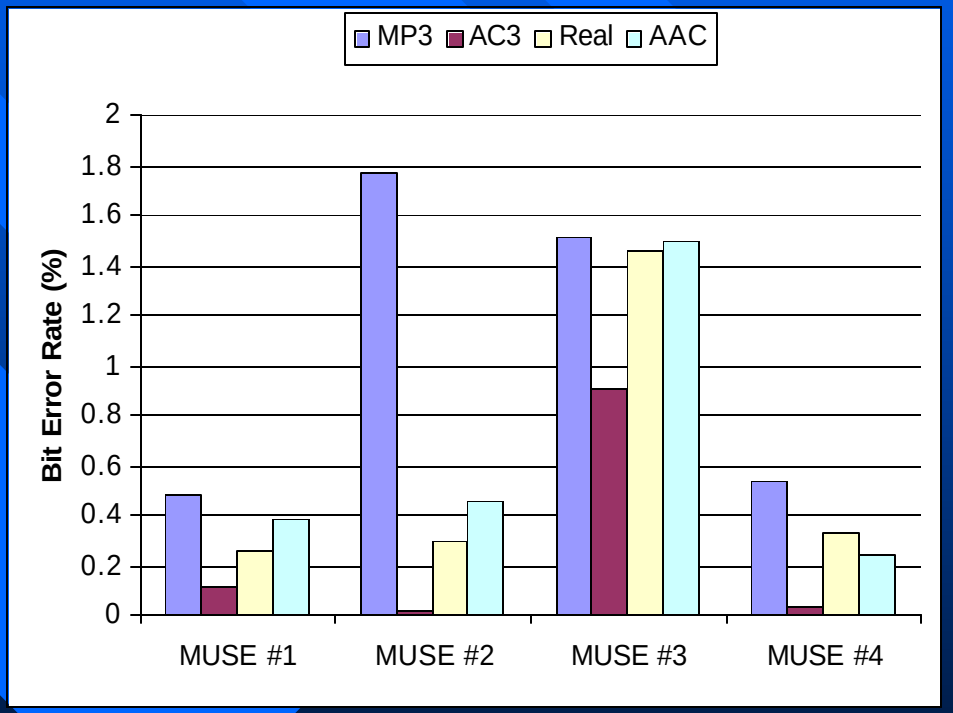
Coding Robustness

- Embedding rate: 42 bits/s. Random text.



Mono

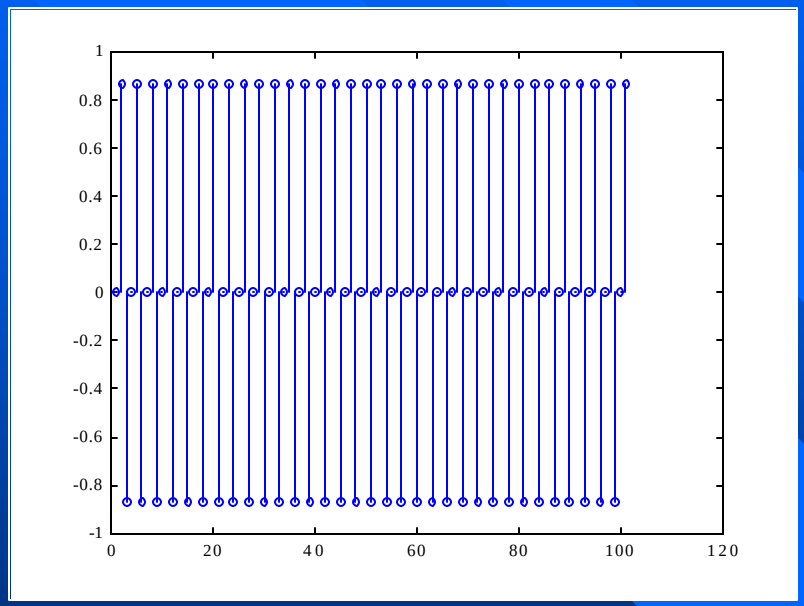
MP-3, AC-3: 56 Kbits/s
Real: 40 Kbits/s (SR: 22.05 Ksamples/s)



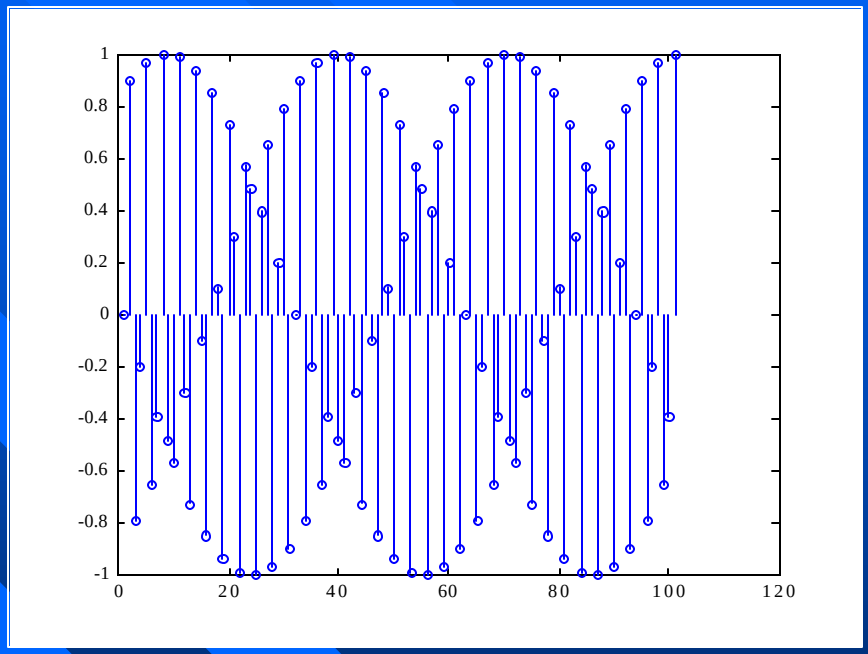
Stereo

MP-3, AC-3, AAC: 96 Kbits/s
Real: 80 Kbits/s (SR: 32 Ksamples/s)

Synchronization Problems



50 Hz sinusoid
sampled at 150 samples/s



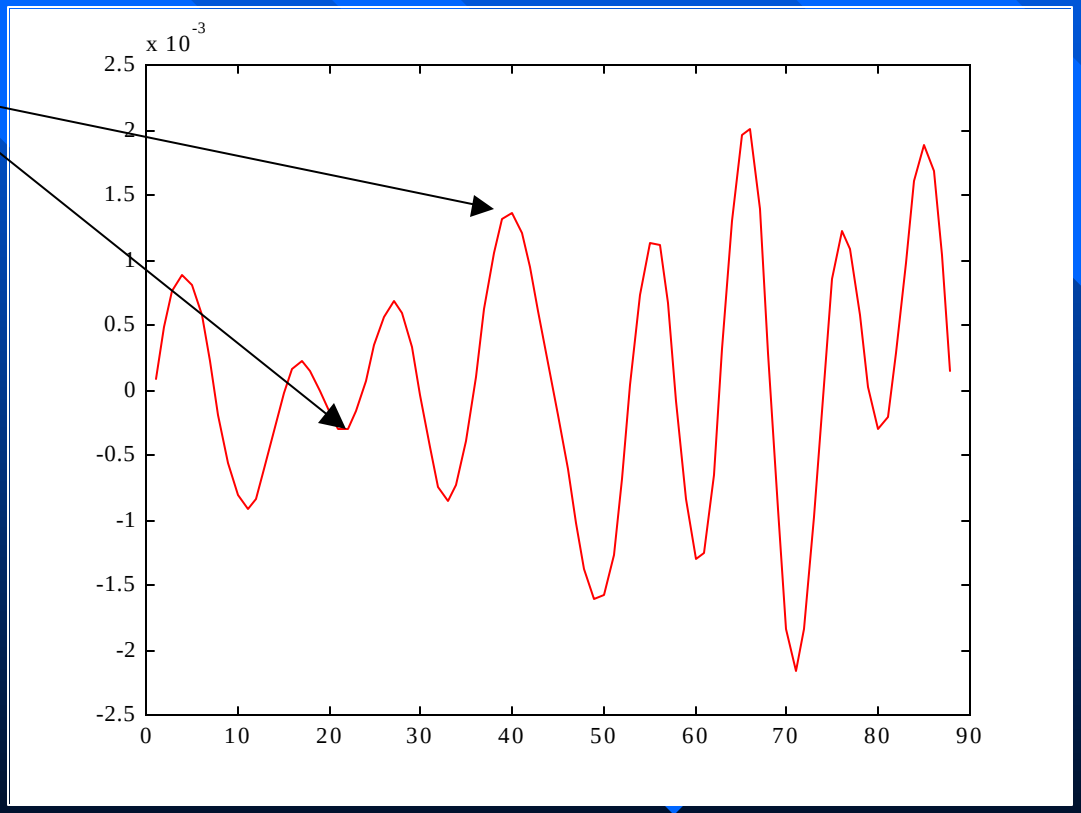
50 Hz sinusoid
sampled at 155 samples/s

- Signal synchronization is needed for accurate extraction of the watermark

Self-Synchronizing Approaches

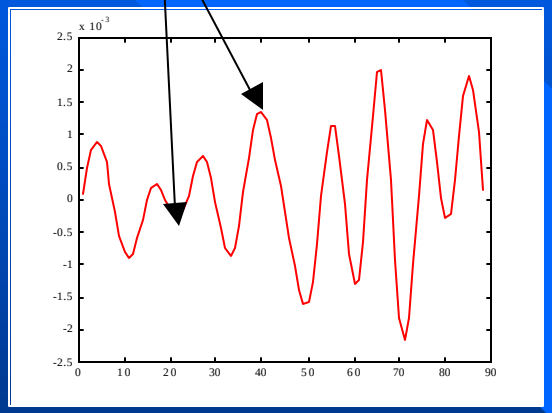
- Use adaptive “markers” to find the data

Local extrema



Self-Synchronizing Approaches

Local extrema



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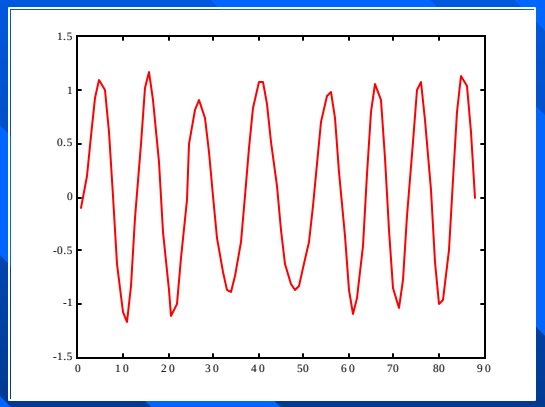

original

Frequency and time domain constrained modification of extremas

Apply any of the known techniques to samples of the signal taken at extrema locations

Comparisons

	Additive Techniques	**Modulation Techniques**	**Self-Synchronizing Techniques**
Masking	Easily implemented	Easily implemented	Moderately difficult to implement
Capacity	Low	High	High
Robustness			
Coding	Moderately sensitive	Robust	Robust
Time scale changes	Sensitive	Sensitive	Robust
Overdubbing	Moderately robust	Sensitive	Sensitive
Realtime Extraction	Moderately fast	Slow	Fast

Conclusion

- Watermarking is still in its infancy but has benefited tremendously from work on human perception
- Audio watermarking field is very active and solutions are being deployed in many applications
- Many challenges remain to meet user needs in some applications