The Asia-Pacific Signal and Information Processing Association (APSIPA) Distinguished Lecture 2012

Recent Development in Perceptual Visual Quality Evaluation

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NANYANG TECHNOLOGICAL UNIVERSITY

Asia-Pacific Signal and Information Processing Association (APSIPA)

- an association to promote broad spectrum of research and education activities in signal and information processing.
- The interest of APSIPA encompasses but not limited to

  signal and information processing, recognition, classification, communication, networking, computing, system design and implementation, security, and technology with applications to scientific, engineering, health, and social areas.

2012 APSIPA Annual Summit & Conference (ASC)

Date: December 3 to 6, 2012

Place: Hollywood, California, USA

- Submission of Proposals for Special Sessions, Forum, Panel & Tutorial Sessions: **May 10, 2012**
- Submission of Full and Short Papers: **June 10, 2012**
- Submission of Papers in Special Sessions: **July 10, 2012**
- Notification of Papers Acceptance: **Aug. 30, 2012**

APSIPA invites proposals to host ASC 2014 and future ASCs.

http://www.apsipa.org/


A picture is worth 1000 words

Question No. 1: Why are pictures important in our life & work?

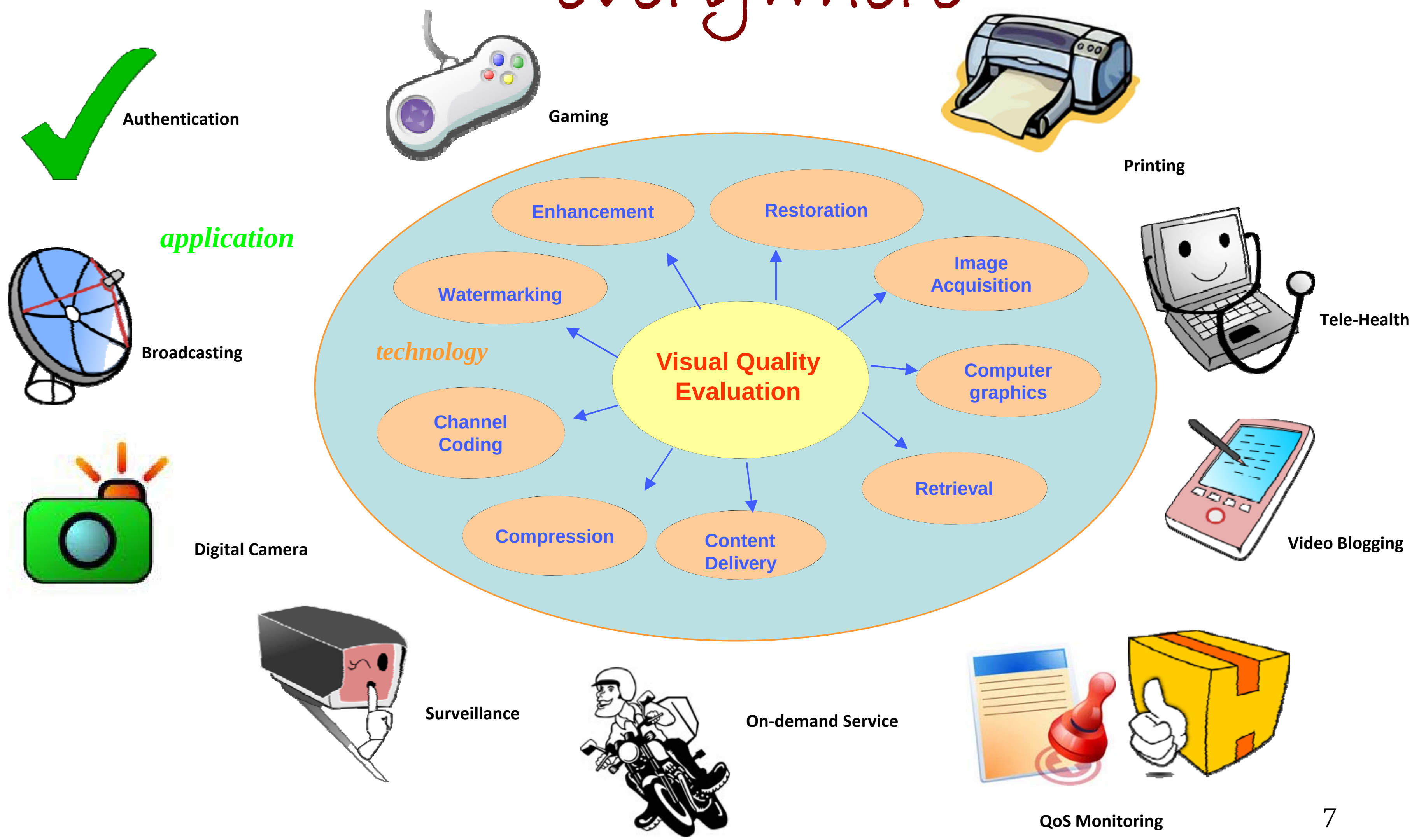
- Physiology/Psychology
  - ~ 50% of cerebral cortex is for vision
  - Vision: major channel for us we to experience the world
- Visual representations: the most efficient way to represent information
  - Even when people speak different languages
- Increasing availability
  - Digital cameras
  - Anytime, everywhere, anyhow…
- Large interest & commercial value

  movies, television, Internet/social/ mobile media, gaming, content search, advertisements, surveillance, politics, scientific research, medical applications, military, …

Question No. 2: Why is picture appreciation by machines important?

- Quality assurance
  - product inspection (PDAs, handphones)
  - test equipment
  - on-line, in-service monitoring
  - visual/multimedia algorithm/system benchmarking
- Technology development & optimization
  - VCD/DVD/HDTV, multimedia
  - computer graphics/animation
  - computational photography
  - visual/multimedia transmission
  - …

Visual Quality Evaluation:
“everywhere”



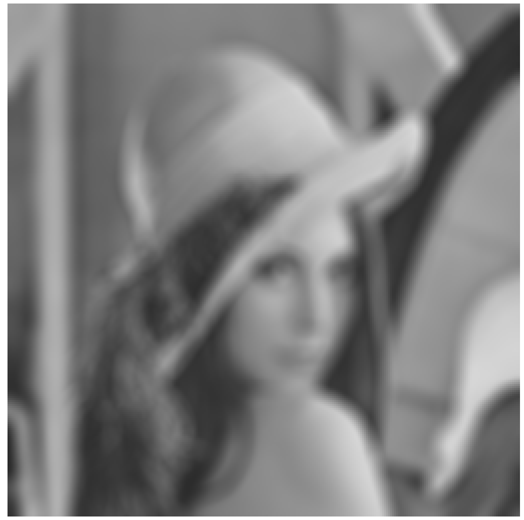
Traditional Visual Signal Quality Measures
(widely used in industries now)

- MSE (Mean Square Error)
- SNR (Signal Noise Ratio)
- PSNR (Peak SNR)
- QoS (Quality of Service)
- or their relatives

These are mathematical measures for fidelity (pixel difference): Not perceptual

Problems with the existing metrics

(a)



(b)

(c)

(a) Original image

MSE=324

(b) Gaussian noise

(c) Brightened

(d) JPG compressed

(d)

(e)

Image Quality Assessment (more examples)

(a)

(b)

(c)

(d)

(e)

(f)

<u>All images have nearly the same MSE/PSNR!!!</u>

The fact

The HVS (Human Visual System): ultimate receiver

of most processed images and video

Gap in most currently systems:

target: human consumption/appreciation

technical design: non-perceptual criteria

Perceptual modeling:

user-oriented

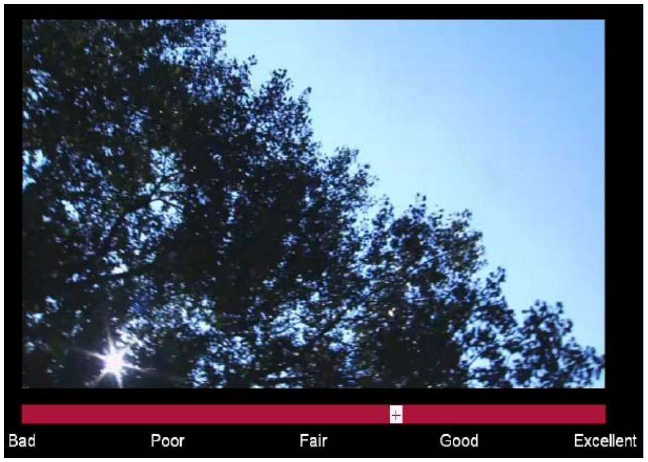
performance booster

Possibilities of Perceptual Evaluation

- **Subjective viewing tests**
  - ITU BT 500 standard
  - MOS (mean opinion score)
  - Shortcomings
    - Expensive, time consuming
    - Not suitable for automatic, in-loop/service, on-line real-time processing

      e.g., encoding, transmission, relaying, etc.
    - Not always reliable

      depending on viewers' physical conditions,
      emotional states, personal experience,
      display context



Solution:

An objective (by machine) measure to emulate MOS!

Machine-based picture processing

Artificial vision

<u>which</u> is <u>where</u>, and <u>what</u> is done and <u>how</u>?

Quality evaluation

Representation: compression

“zipping” & restoration

Pixel manipulations

cropping, edition (addition/subtraction/size change)

object boundary detection, edge enhancement

histogram equalization, …

difficulty

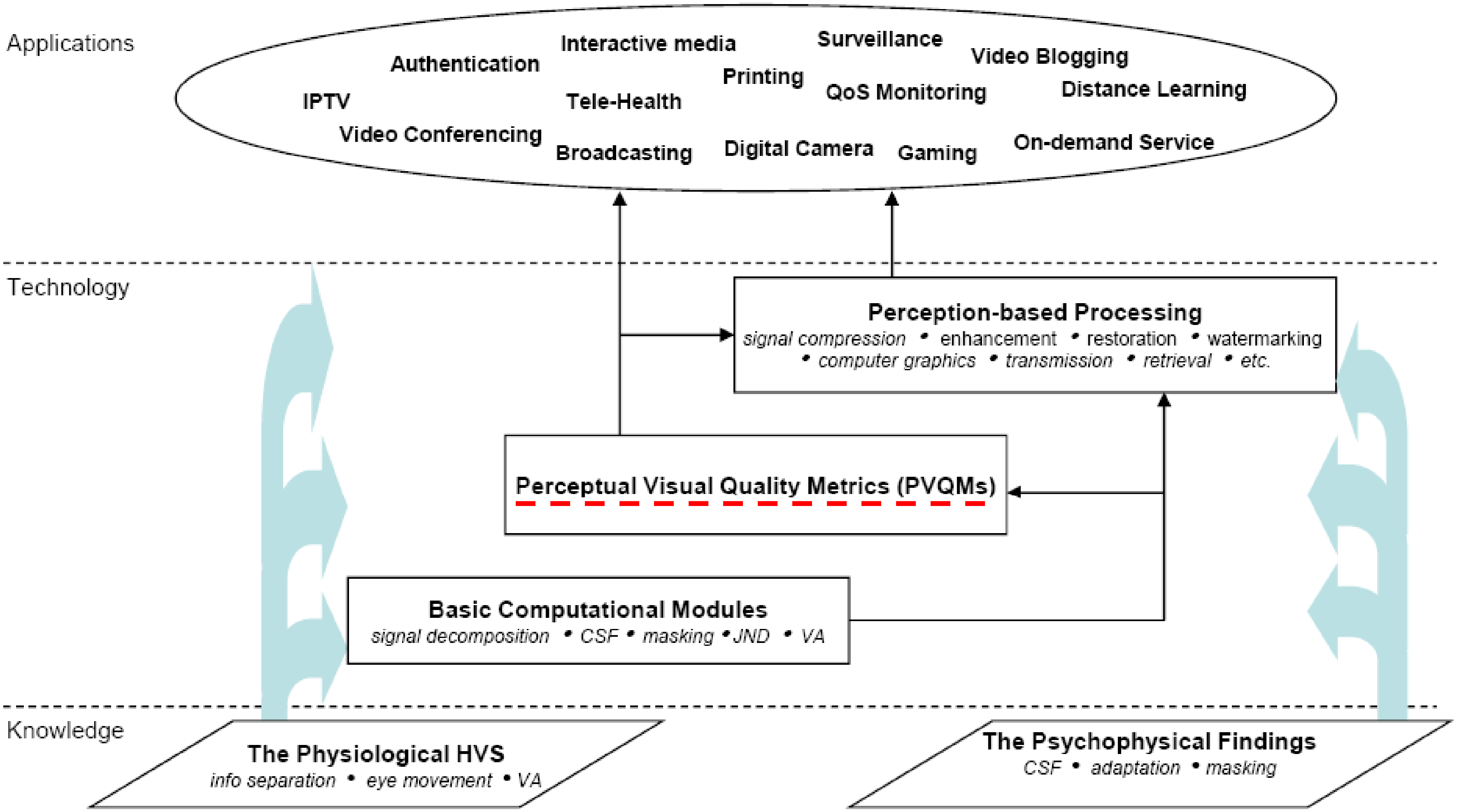
Picture quality evaluation

"Video quality is in the eye of the beholder"

- 1st-party evaluation
  - by the photographer or image maker
- 2nd-party evaluation
  - by the subject of an image
- 3rd-party evaluation
  - by neither the photographer nor the subject
  - general and most meaningful situation

Perceptual Picture quality evaluation

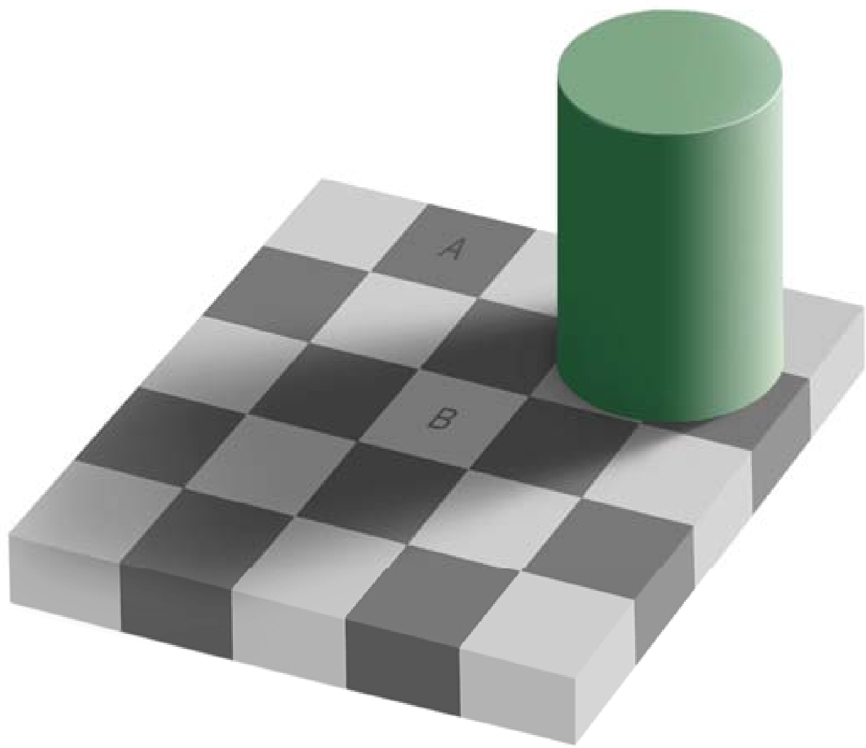
- **Objective visual quality metrics (VQMs)**
  - MOS prediction
  - HVS modeling
    - physiology
    - psychophysics
  - Difficulties
    - inadequate understanding of the HVS
    - difficulty in modeling
    - computational complexity

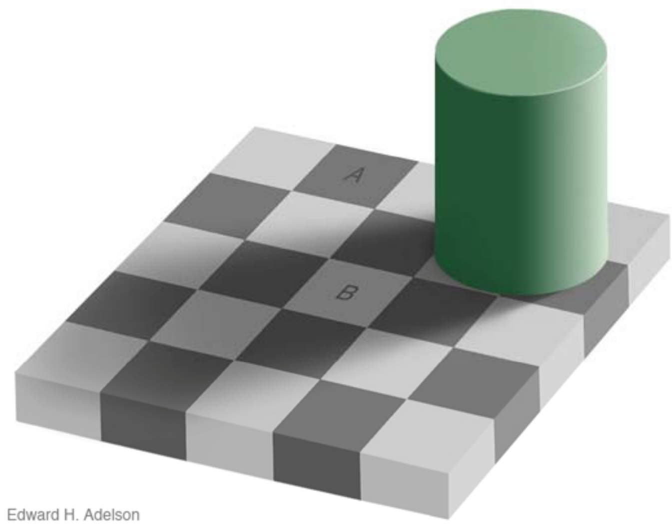

Applications
IPTV
Authentication
Interactive media
Surveillance
Video Blogging
Printing
Tele-Health
QoS Monitoring
Distance Learning
Video Conferencing
Broadcasting
Digital Camera
Gaming
On-demand Service
Technology
Perception-based Processing
signal compression • enhancement • restoration • watermarking • computer graphics • transmission • retrieval • etc.
Perceptual Visual Quality Metrics (PVQMs)
Basic Computational Modules
signal decomposition • CSF • masking • JND • VA
Knowledge
The Physiological HVS
info separation • eye movement • VA
The Psychophysical Findings
CSF • adaptation • masking

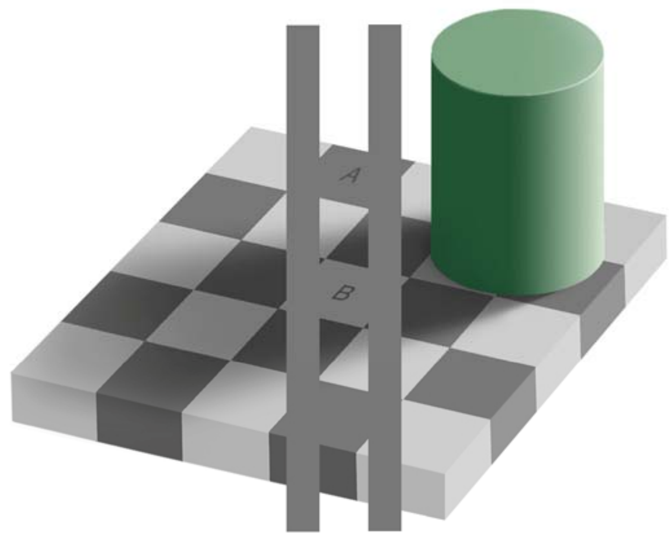
Outline of the rest of this talk

1. Relevant HVS Facts toward images
2. Basic Computational Modules
3. Perceptual Visual Quality Metrics (PVQMs)
4. Metric Benchmarking
5. Summary & Further Discussion

Which square is brighter, A or B?







Adelson's "Checker-shadow illusion"

http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html

Related HVS Properties

- Exploiting the relevant properties of the human visual system (HVS) for assessing quality of visual signals (image and video)
  - Sensitivity to structural changes
  - Color contrast
  - Masking effects
  - Saturation effect
  - Role of visual attention

Related HVS Properties (cont.)

- **Sensitivity to structural changes**: Features like edges, contours play a key role in visual quality assessment

Original image

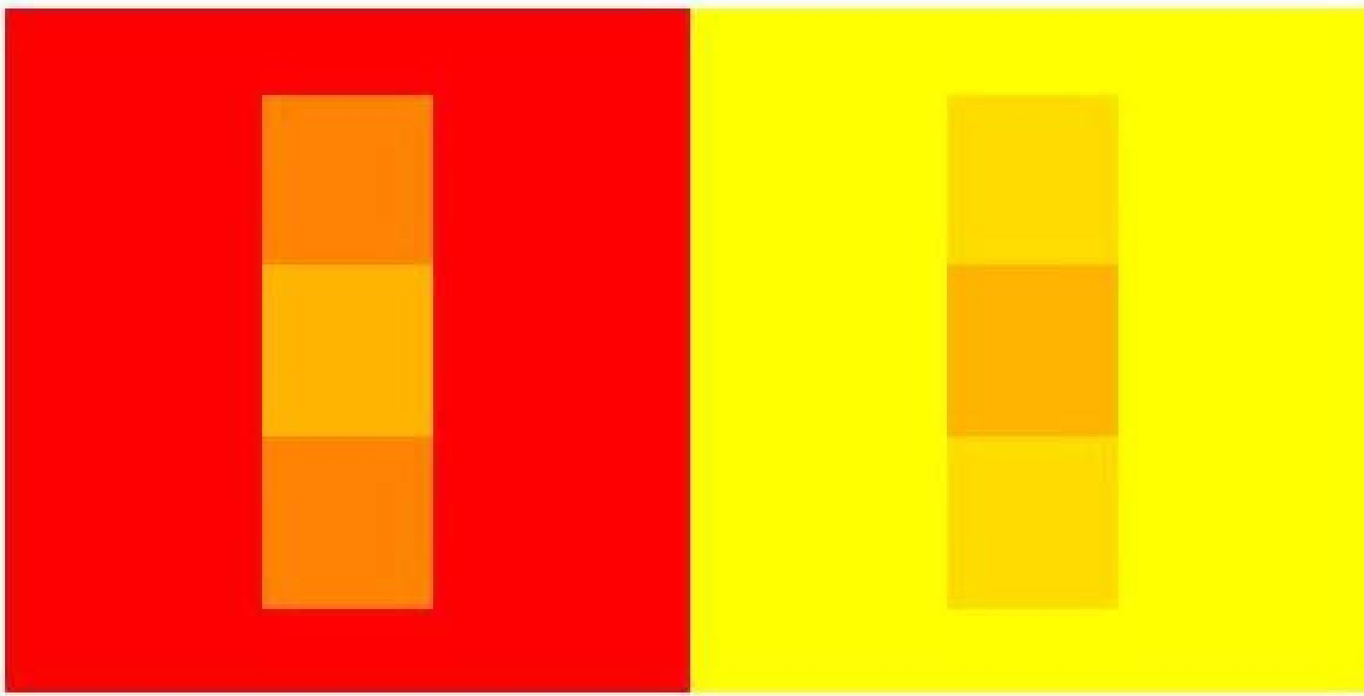
Noisy image

Blurred image

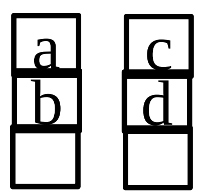
Lower visual quality due to edge damage

Related HVS Properties (cont.)

- **Color Contrast**: Background color can affect visual perception [http://www.psy.ritsumei.ac.jp/~akitaoka/shikisai2005.html]a



It appears that a = d or b = c in color, but actually b = d!!



Related HVS Properties (cont.)

- **Masking effects**: Visual impact of the same distortion can be different depending on signal content

(a)

(b)

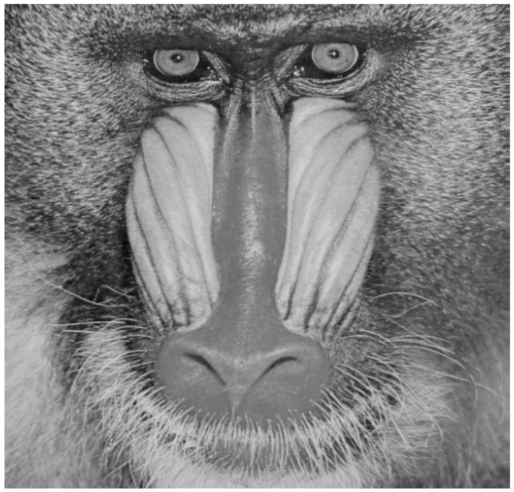
More annoying to the eye

Texture masking

Related HVS Properties (cont.)

- **Texture Masking:** Effect of distortion is reduced due to texture

(a)



Original image

(b)

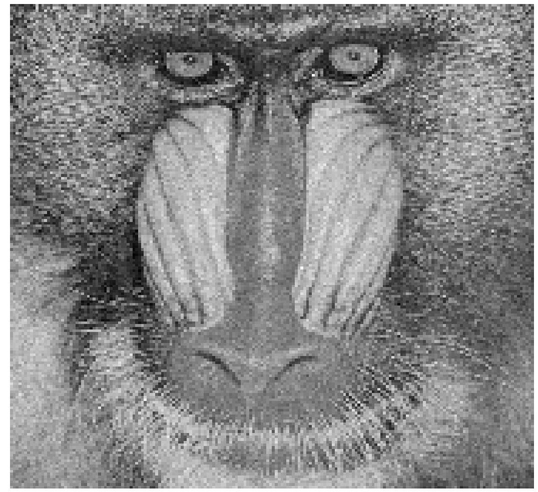
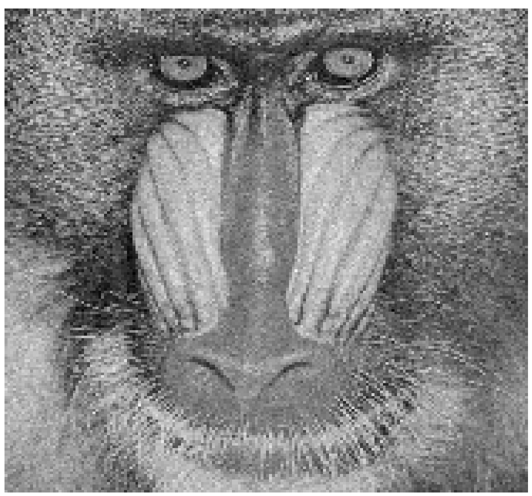


Image with lowest distortion

(c)



(d)

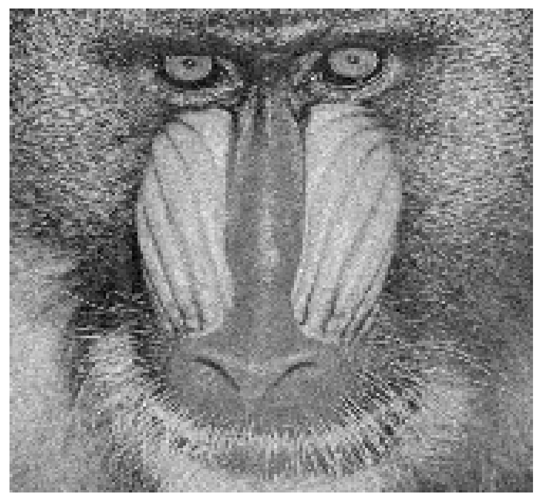


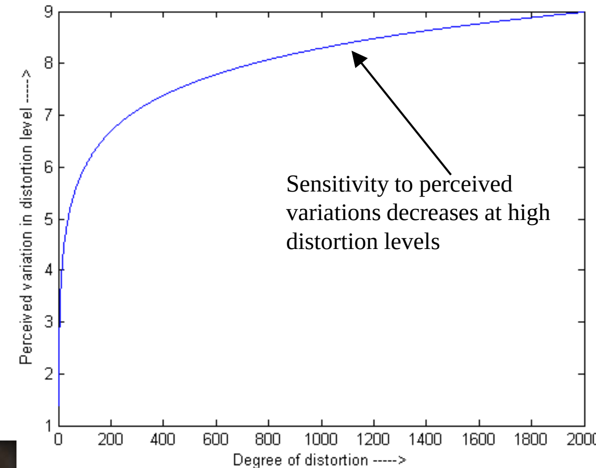
Image with highest distortion

Related HVS Properties (cont.)

- **Saturation effect**: Sensitivity to perceived distortion decreases at high distortion levels

Original image

(a)



(b)

(c)

Higher level of blurring than the image on left

Perceived distortion level in the two images is however nearly the same

Related HVS Properties (cont.)

- **Role of visual attention**: Distortion in regions attracting the human attention are more annoying than that in non-attentional ones

(a)

Original image

(b)

Attentional region (face) distorted

(c)

Non-attentional region distorted

Observe that **distortion** in image (b) is **more annoying** than in image (c). This is because ‘face’ is **attentional region** as compared to ‘table’

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   - Just-noticeable difference (JND)
   - Visual attention
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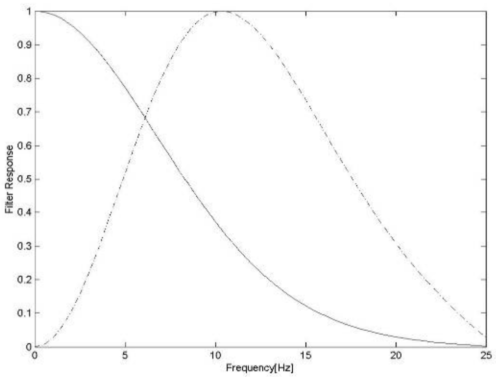
4. Metric Benchmarking
5. Conclusions and Discussion on Future Work

Temporal Decomposition

- Physiological evidence
  - two main visual pathways
  - visual cortex
- Signal decomposition
  - Implemented as FIR/IIR filters
    - sustained (low-pass) channel
    - transient (band-pass) channel



Spatial Decomposition

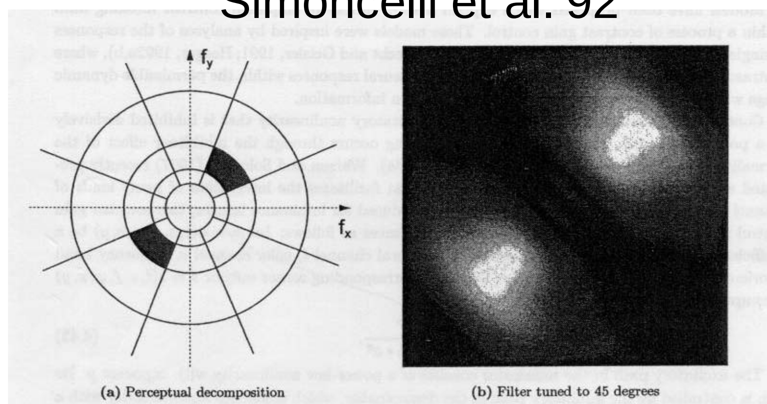
– Filters

  Gabor, Cortex, wavelets

  Gaussian/sterrable pyramid

– Stimuli: orientations, frequencies

Simoncelli et al.'92

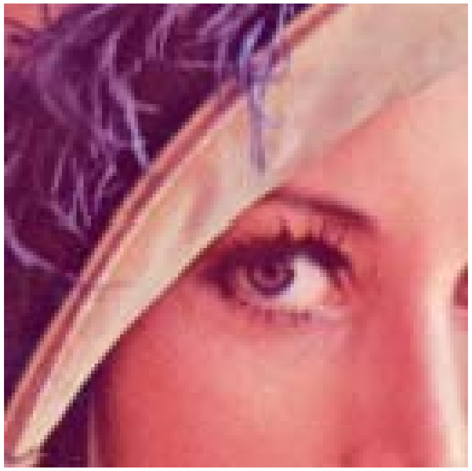


(a) Perceptual decomposition (b) Filter tuned to 45 degrees

Just-noticeable Difference (JND)

- the visibility threshold below which any change cannot be detected by the human visual system (HVS)
  - e.g.,75% of viewers
- "just-noticeable distortion": not necessarily distortion
- JND estimators
  - DCT/DWT subbands
  - Pixel domain

Demonstration of JND Profile via Noise Shaping



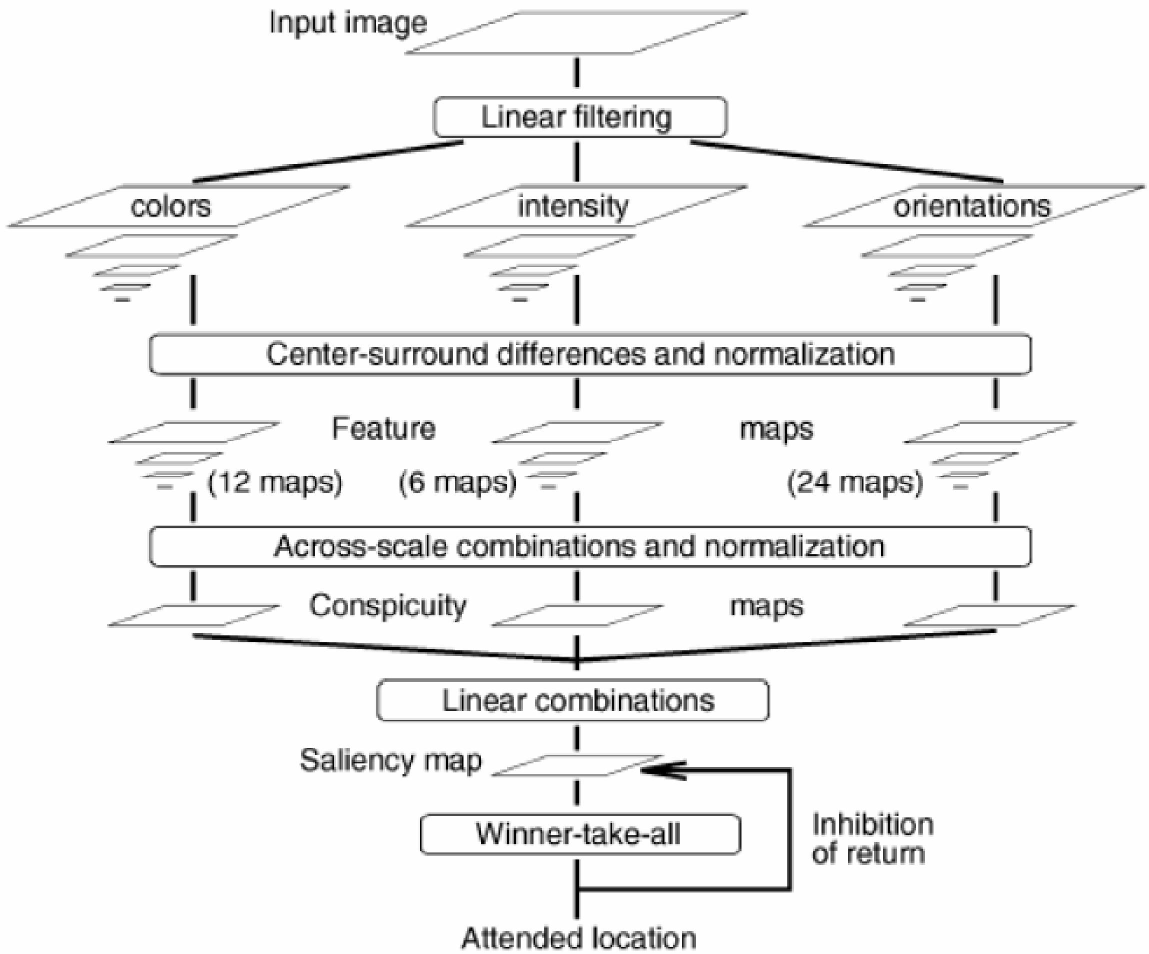
(a) Original Image

(b) Noise Injection with Yang, et al.'05 (PSNR: 29.15 dB)

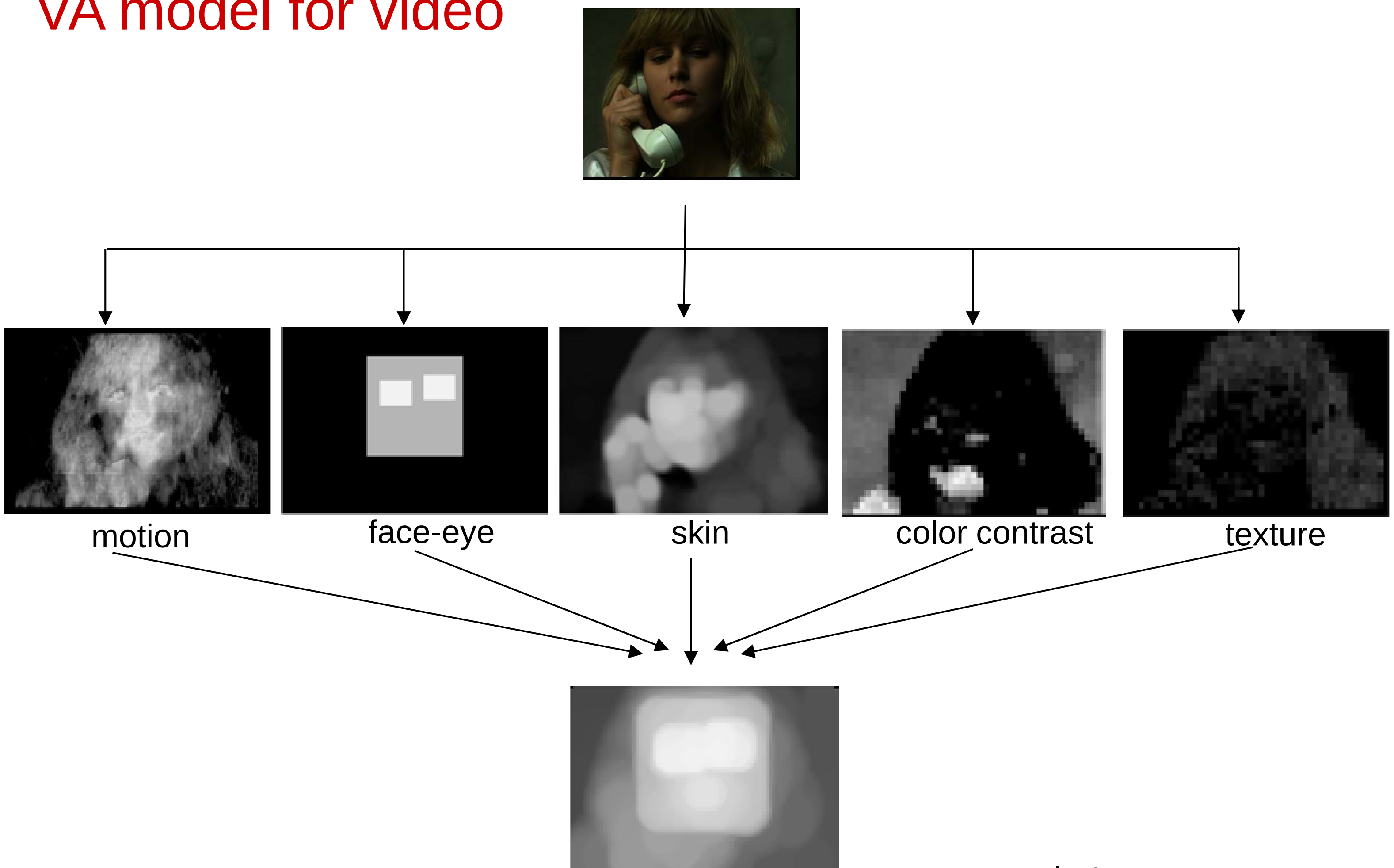
Better image quality for same level of noise energy

(c) Random Noise Injection (PSNR: 29.21 dB)

Itti’s Bottom-up Visual Attention (VA) Model



VA model for video



Lu, et al, ’05

Verification with eye tracking

various eye trackers

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Visual Quality Gauge

Why a traditional metric fails

$$MAE = \frac{1}{XY}\sum_{x-1}^{X}\sum_{y=1}^{Y}\left|\Delta d(x,y)\right|$$

$$MSE = \frac{1}{XY}\sum_{x-1}^{X}\sum_{y=1}^{Y}MAE^{2}$$

$$PSNR = 10\lg\frac{A^{2}}{MSE}$$

Major reasons for failure:

(1) Not every change in an image is noticeable;

(2) Not every pixel/region in an image receives the same attention level;

(3) Not every change leads to distortion (otherwise, many edge sharpening and post-processing algorithms would have not been developed);

(4) Not every change yield a same extent of perceptual effect with a same magnitude of change (due to spatial/temporal/chrominance masking).

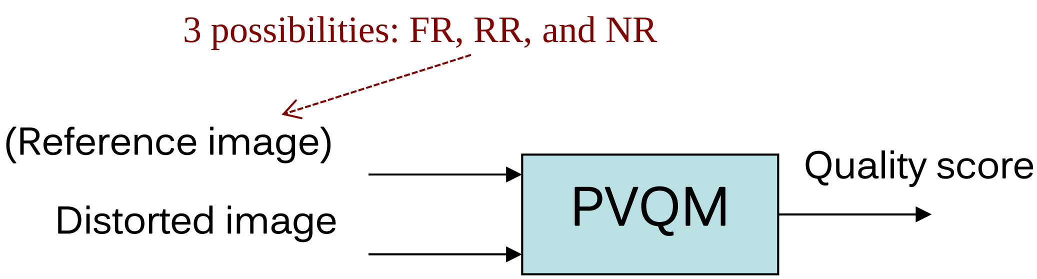
Classification for PVQMs

According to methodology:

- **Vision-based Metrics**
- **Signal-driven Metrics (more often used now)**
- **Learning based Metrics (emerging)**

According to reference requirement:

- **Full-reference (FR) Metrics**
- **Reduced-reference (RR) Metrics**
- **No-reference (NR) Metrics**



The first two classes of metrics:

Objective Image Quality Assessment

Vision Based Model

- Early approach**:** tries to model HVS
(**Pioneers: Lubin, Daly, Watson**)

- Generally based on data from psychophysical experiments

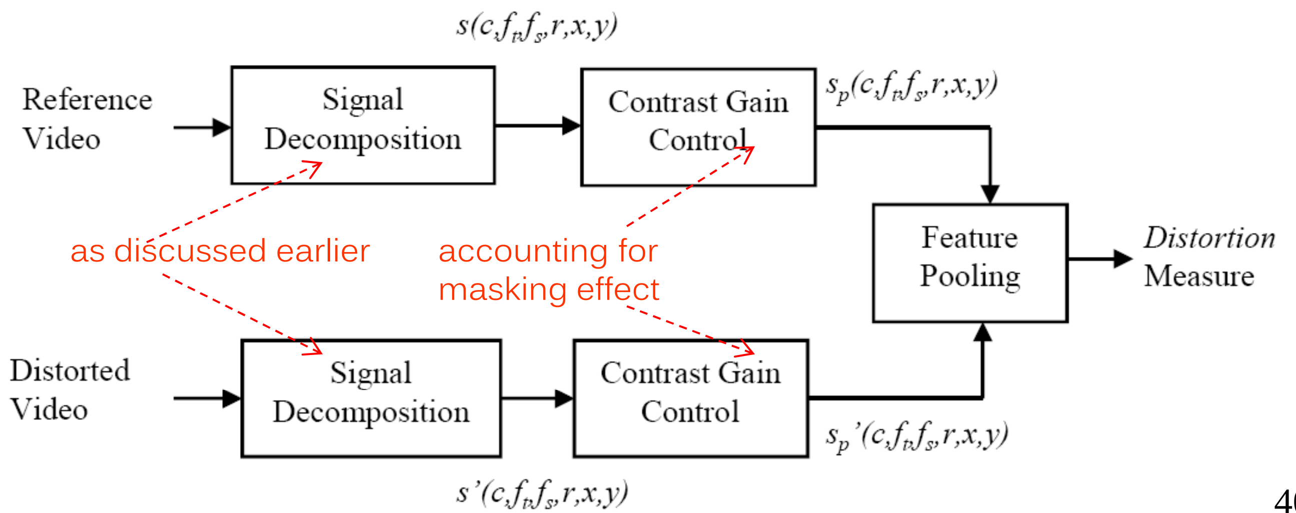
Signal Driven Model

- Based on extraction and analysis of image features

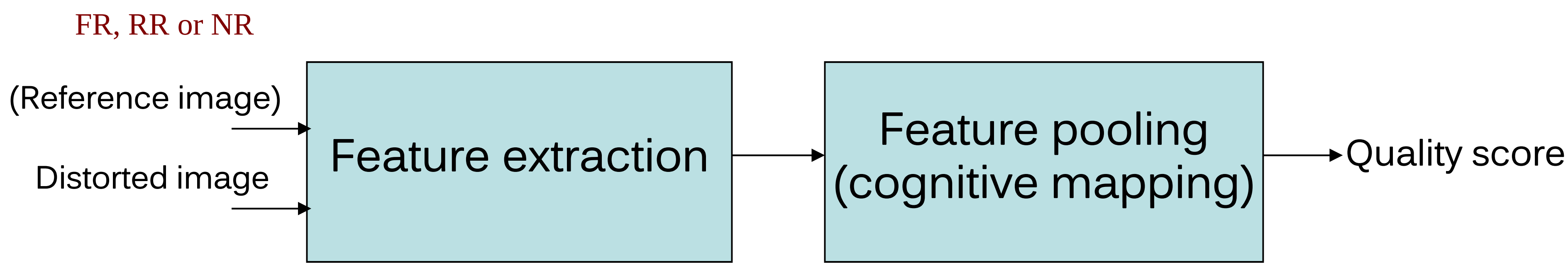
- Focus is on image content and distortion analysis rather than fundamental vision modeling

Vision-based Models

- attractive in principles: to incorporate relevant HVS properties pertaining to visual quality
- Major limitation:
  - limited understanding of the HVS and its intricate mechanisms
  - Metrics can be complex and computationally expensive



Signal Driven Models



may also incorporate appropriate HVS properties, like JND, VA, various masking effects, and so on.

Recently, more research effort for signal driven models

An emerging class of metrics: machine learning-based approaches

To tackle problems for feature pooling in spatial or spatiotemporal domain

- Currently-employed techniques:
  - simple summation
  - Minkowski combination, linear (i.e. weighted) combination
  - Visual attention based weightings
- Problem: impose constraints on the relationship between features and quality score
  - A simple summation or averaging of features implicitly constraints the relationship to be linear.
  - Minkowski summation for spatial pooling of the features/errors implicitly assumes that errors at different locations are statistically independent.

Machine learning as an alternative for feature pooling

- machine learning: general, more systematic and reasonable
- avoid assumptions on the relative significance and relationship of different distortion statistics (i.e. feature changes)
- more databases available for training
- effective feature extraction: still a key
- Support Vector Regression: encouraging results

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Metric Benchmarking

- experimental results for 6 oft-used full-reference image quality metrics
  - SSIM, VIF,IFC, VSNR, MSVD, PSNR
- 7 pubic image quality databases
  - LIVE, TID, A57, WIQ, CSIQ, IVC, Toyama

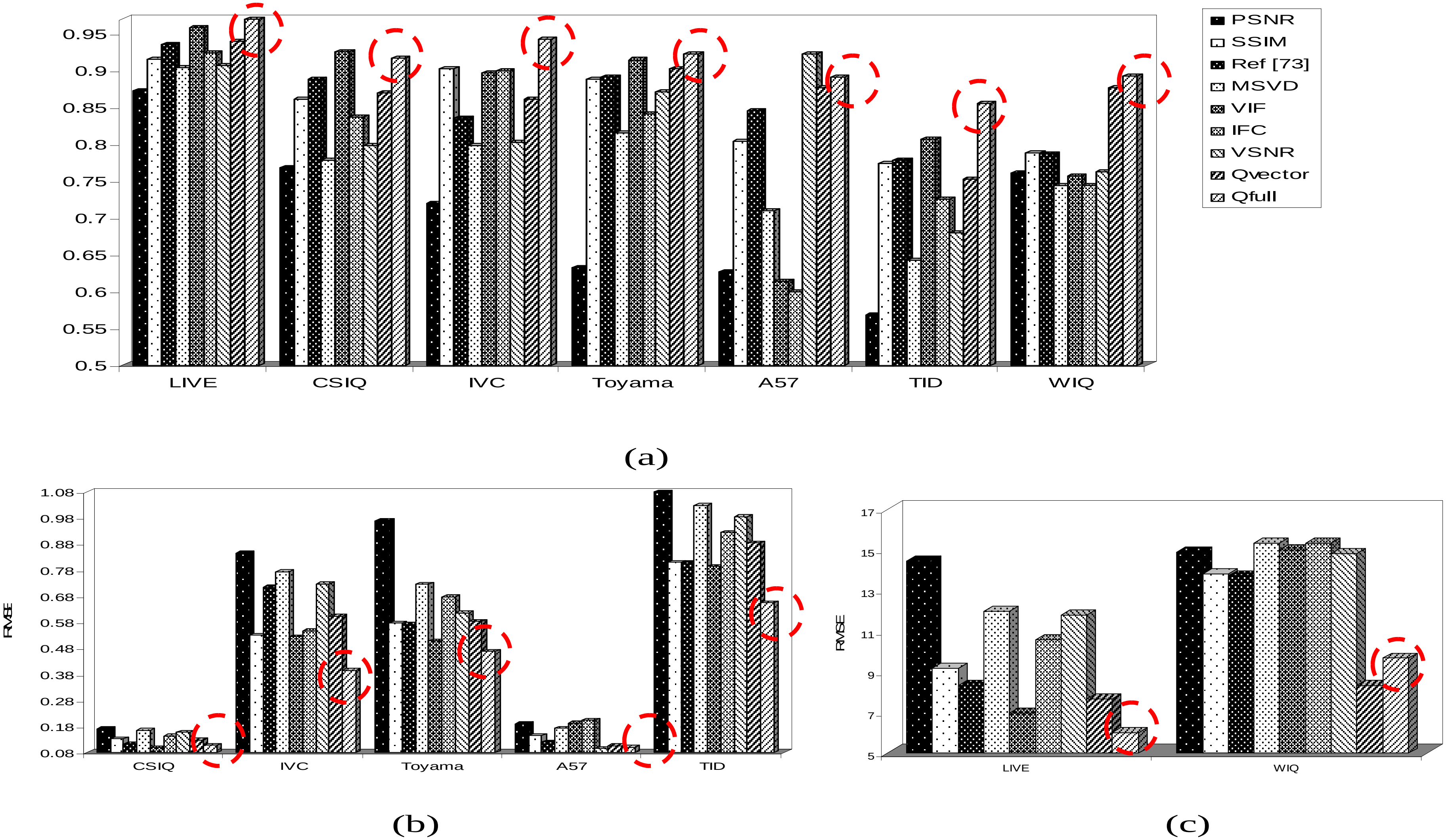
Description of image databases

Name	n_0	n	R	$S_{(range)}$	DistortionTypes
LIVE	29	779	(see Notes)	$DMOS_{(0-100)}$	JPEG-2K compression;JPEG compression; White Gaussian Noise; Gaussian blurring; Rayleigh-distributed bit errors of JPEG -2K stream or Fast fading distortion
CSIQ	30	866	512x512	$DMOS_{(0-1)}$	JPEG compression; JPEG-2K compression; global contrast decrements; additive pink Gaussian noise; additive white Gaussian noise
IVC	10	185	512x512	$MOS_{(0-5)}$	JPEG-2K compression; JPEG compression; LAR (locally adaptive resolution) coding; blurring
Toyama	14	168	768x512	$MOS_{(1-5)}$	JPEG-2K compression (with JasPer s/w); JPEG compression (with cjpeg s/w)
A57	3	54	512x512	$DMOS_{(0-1)}$	LH-subband quantization of a 5-level DWT with 9/7 filters; additive Gaussian white noise; baseline JPEG compression; JPEG-2K compression; JPEG-2K compression with greater to fine spatial scales to preserve global precedence; blurring
TID	25	1700	512x384	$MOS_{(0-9)}$	additive Gaussian noise; spatially correlated noise; masked noise; high frequency noise; impulse noise; quantization noise; Gaussian blur; image denoising; JPEG compression; JPEG-2K compression; JPEG transmission; JPEG-2K transmission; non eccentricity pattern noise; block-wise distortion of different intensity; mean shift; overall contrast change
WIQ	7	80	512x512	$DMOS_{(0-100)}$	wireless imaging artifacts, which are not considered in other publicly available image quality databases

n_0: number of original images;
n: number of test images;
R: image resolution (Notes: LIVE has many images of size 768x512, but also of other size like 480x720, 632x505, 634x505, 618x453 and 610x488);
S: type of subjective quality score.

FR signal-driven image quality metrics

Performance Comparison with Learning-based Metrics



(a) C_P (Pearson correlation) comparison on different image databases, (b) RMSE (root MSE) for CSIQ, IVC, A57 & TID databases and (c) RMSE for LIVE and WIQ databases

Narwaria & Lin'10

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Summary & Further Discussion

- Various perceptual quality metrics developed in past years
- Benefits of perceptual modeling
  - ✓Filling the gap in current technology: "***customer oriented***"
  - ✓New dimension of improvement in many visual processing tasks
    - ❖room for further improvement with existing technology: ***diminishing***
  - ✓Differentiating factor for commercial products

Possible further work:

- chrominance effects
  esp. for non-coding distortion
- joint modeling with other media
  audio, text, and so on
- mobile comm applications
  application-specific
- adaptive watermarking
  - authentication
  - error resilience
- streaming, transmission & networking
  - priority labeling
  - resource allocation
  - global optimal solution
  - pricing system
  - taking bit stream info into account
- other possibilities
  - medical images (e.g., TeleHealth)
  - e-learning
  - computational photography

Emerging new forms of visual signal

- Mobile media

- HD (high-definition) TV

- 3D TV (w/i & w/o goggles)

Different views on the role of visual attention (VA)

- no doubt: VA is important to HVS perception
- however, it has been argued that VA consideration is not always beneficial (at least for simple weighting)– Ninassi, et al.'07
- distortion may change the subjects' eye fixation and duration– Vu, et al.'08
- visual quality may be influenced by not only attentional regions, but also non-attentional ones-- You, et al.'10
- still an open issue for research

Issues Related to Viewing Distance (L)

- limited research on the influence of L
- VSNR: L=3.5 times of the image height, and claimed to be reasonable for typical viewing conditions
- Multi-scale approach:
  – SSIM: downsampling both reference and test images into different resolutions.

    However, the multi-scale SSIM does not always yield better results than its single-scale version
  – IFC and VIF: steerable pyramid transform.

Issues Related to Viewing Distance (L) -cont'd

- Still a challenge for future research to account for viewing conditions (display resolution, ambient illumination and viewing distance)

Applications to computer graphics

- computer graphics: actively developing areas (interactive media)

- computational complexity

"The goal of computer graphics isn't to control light, but to control our **perception** of it. Light is merely a carrier of the information we gather by perception."

J. Tumblin and J. A. Ferwerda, 2001

Closely-related References (for further reading)

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Thank you for your time !

Questions?