Digital Image Processing

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Outline

- Difference from 1D signal processing
- Sub-fields and types of problems
- Applications
- Useful Background

Differences from 1D Signal Processing

- Take care of spatial relationships, e.g. spatial frequency, notion of shape
- Too much information – req. “feature” extraction
- Noise assumptions for 1D signals don’t always model image noise well
- **No standard statistical models to categorize images, every problem is different** ☹
- 3D scene → 2D images, can be occlusions, many problems are ill-posed

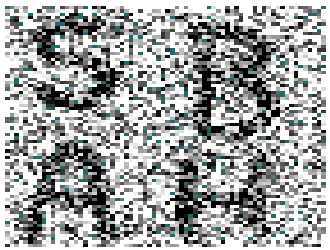
Sub-Fields

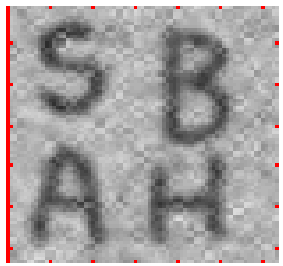
- Compression & Communications
  - Lossy compression, remove high frequency, JPEG
  - Transmit: varying bandwidth requirements, delay sensitive, tolerates errors
- Image Processing: image acquisition (to retain “most” information) & processing to improve image quality
- Tomographic reconstruction
- Image Analysis: Estimate/detect (inference) from images
- Pattern Recognition: only detection/classification problems
- Computer Vision: 2D images → 3D scene estimation

Image Processing

- Image Restoration
  - Deblurring
  - Denoising
- Filtering
- Image enhancement
    - e.g. contrast enhancement: histogram equalization
- Feature extraction
  - edges, texture, PCA, motion, local histogram, filtered o/p (e.g. Gabor), wavelet…
- Image Acquisition Issues

Image Proc: Denoising





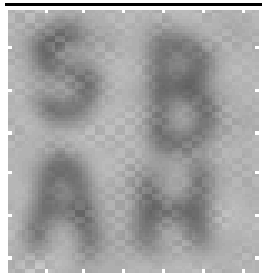


Image Proc: Deblurring

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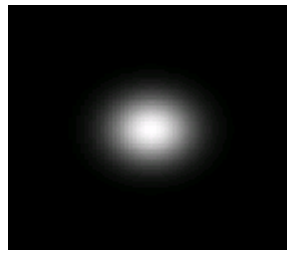


Blurred image

Restored image

PSF

De-blurring: Deconvolution operation
Can be blind (PSF not known) or not-blind

Image Proc: Acquisition

- Sensors, e.g. CCD
  - Higher resolution (improving sampling rate)
  - Higher fidelity (more quantization bits, low noise)
  - Improving speed of acquisition
  - Low power devices
  - Camera design (projective geometry, lens physics)
  - Panoramic cameras – with 360^{o} field of view
- Image interpolation e.g. digital zoom
- Decimation

Image Proc: Feature extraction

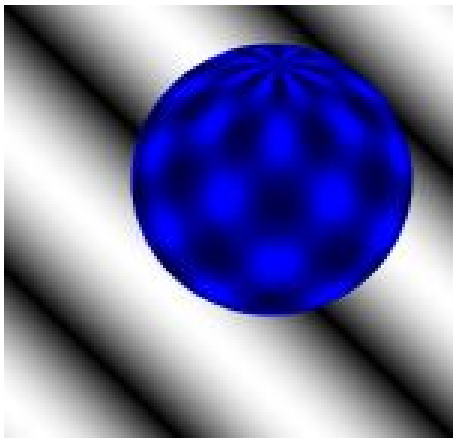
- Intensity
- Edges – threshold spatial gradient
- Texture – repeated basic “primitives” & spatial relation, view at different scales
- Motion – Threshold frame difference
- Motion – Optical flow (where did pixel *(i,j)* move)
- Shape, Local histogram, PCA, image transforms

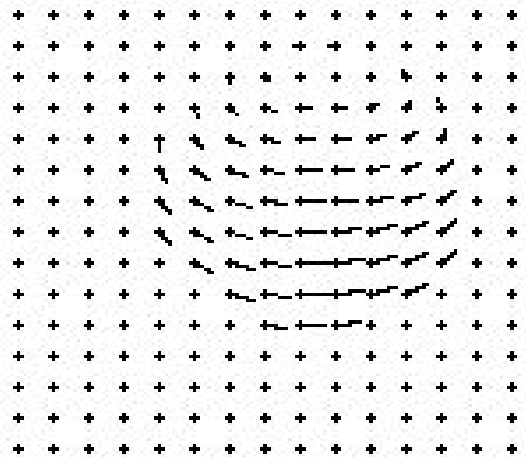
Image Proc: Textures

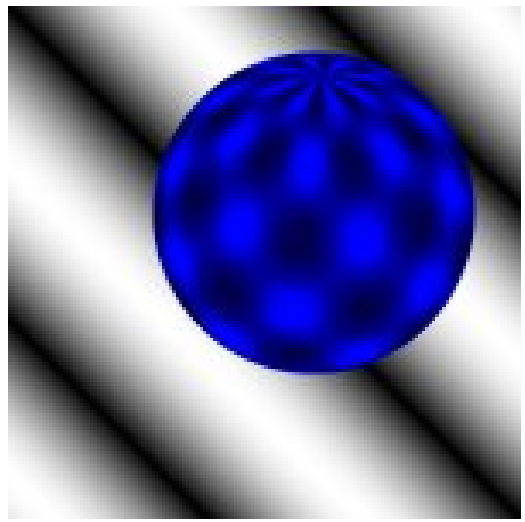
Coarse texture

Fine texture

Optical Flow

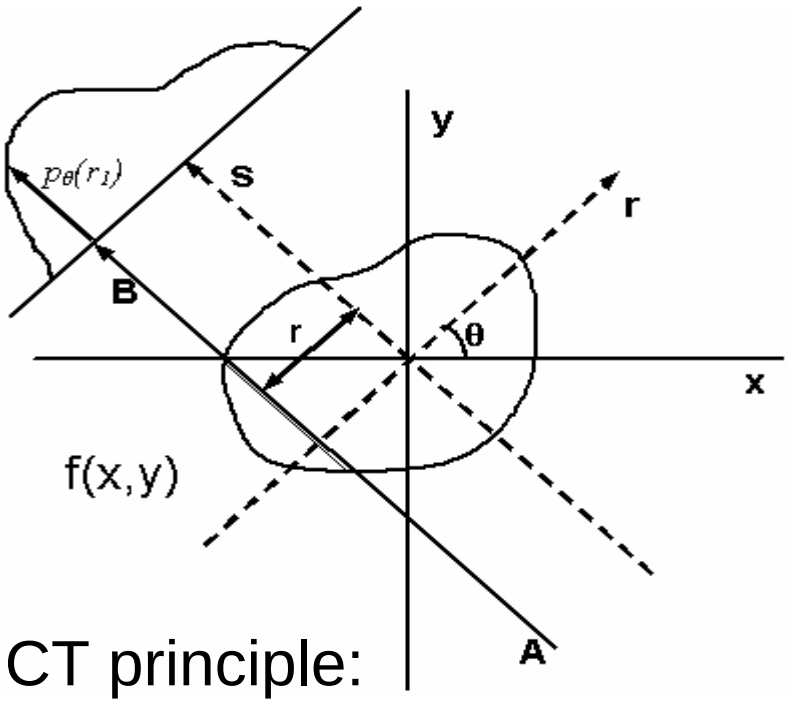






Tomographic Reconstruction

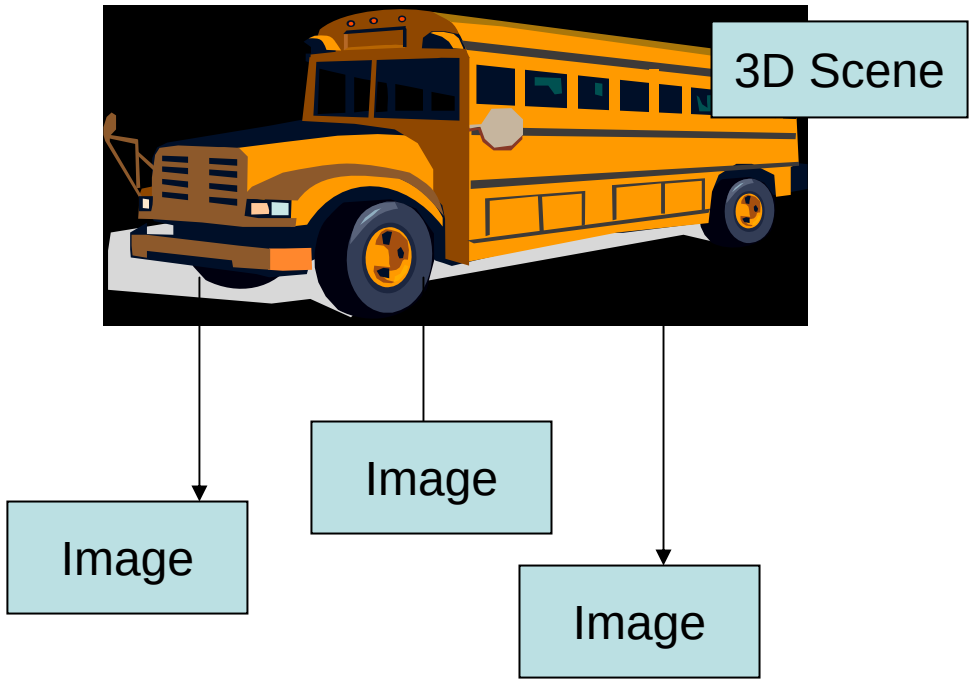
- Getting the image of a cross section from projections at different angles, e.g. CT, PET



CT principle:
Projection Slice Theorem

CT reconstruction of a
Brain cross-section

Image Analysis/ Comp Vision



One image - Segment, Recognition, Edge detect & get contour
Two images – Registration, Optical flow, Get 3D structure (stereo)
Time sequence - Tracking, Structure from Motion, Change Detection

Image Analysis

- Segmentation
  - Estimate outer contour (boundary) of the object from the image
  - Or: classify image regions as foreground/background

- Registration
  - Estimate a **global** transformation (Affine, Similarity, Euclidean) relating 2 images
  - taken from different views, different modalities or different times

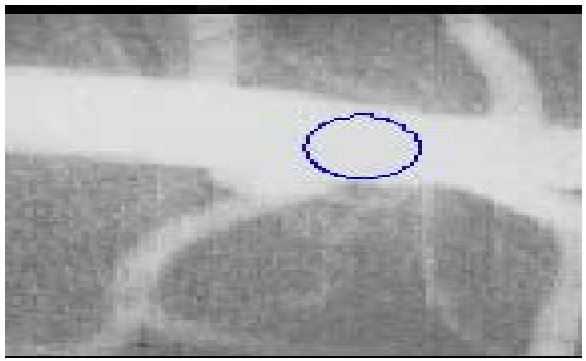
Image Analysis (contd.)

- Shape – geometric information after removing scale, translation, rotation
- Recognition / Classification / Detection
  - e.g. Faces, Objects, Vehicles, Activity (video)
  - Use intensity, shape, texture, motion,…
- Tracking – Estimate from a time seq. of images
  - Global motion **or**
  - Global motion & Local deformation (shape change)
  - Use all info from past and use a prior statistical models for “state” change
  - Change detection – change in the system model

Image Analysis (contd.)

- Representing Shape
  - Landmarks – points of high curvature or intensity or motion blobs or of “interest”
  - Continuous curve – parametric finite dim. representation e.g. B-spline, angle repr.
  - Continuous curve – infinite dim. representation – level set method

Image Analysis: Segmentation



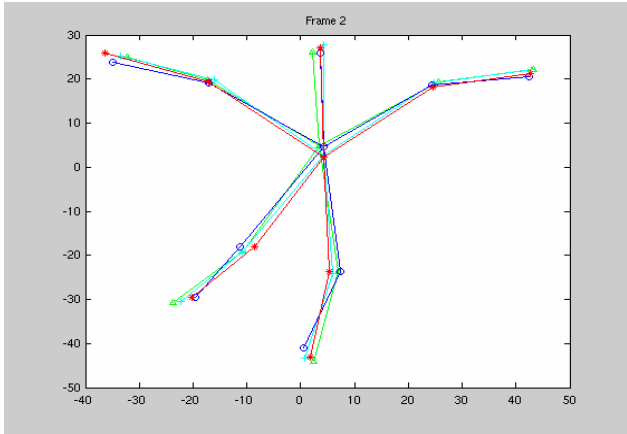
- From Sethian's website: http://math.berkeley.edu/~sethian/level_set.html

Image Analysis: Tracking

- Fish :
  - “Feature”– Image intensity,
  - Shape repr.: Level set method
  - Initialiazation: Segmentation

- Group of People
  - “Feature” – Motion detection
  - Shape repr: Landmark shape
  - Also do change detection

- Human actions
  - “Feature”: local PCA
  - Shape: Landmark



- Leaf (CONDENSATION algorithm):
  - “Feature”: edges
  - Shape repr: B-spline

- Beating Heart: 3D image sequence

Pattern Recognition

- Change detection in an image sequence
  - Detecting abnormal patterns/shapes
  - Detecting changes in motion patterns
- Classification, retrieval, recognition
  - Faces, objects, activities, handwriting,…
- Shape analysis, matching
  - Learning statistical models for shapes of groups of points or of continuous contours, their dynamics over time
  - Matching: shape classification

Recognition

- Faces: AT&T database
- Objects: COIL database

- Activity recognition, Abnormality detection

Computer Vision

- 2D images → 3D scene reconstruction
- Camera models – perspective, orthographic, affine,…
- 3D reconstruction from set of 2D images using
  - images from a single moving camera (structure from motion)
  - or multiple static cameras (stereo)
  - to get 3D coordinates of scene points
- Tracking in 3D – estimating 3D object location as a function of time

Applications: Medical Imaging

- Reconstructing an image from projections e.g. CT scan, PET, MRI
- **Computer Aided Detection (CAD)**, e.g. detecting a tumor
- **Segmentation** e.g. arteries, brain grey matter, tumor
- **Registration** of images from diff modalities or viewpoints
- **Tracking:** use in image-guided surgery
- **Deblurring, Denoising** e.g. ultrasound is very noisy.

More Applications

- **Defense**
  - Automated navigation of UAVs (Unmanned Air Vehicles)
  - Video stabilization
  - Target segmentation, recognition, tracking
  - Compression & transmission

- **Surveillance / Security**
  - Detecting “abnormal” activity in images
  - Building normalcy models: statistical models
  - Requires feature extraction, tracking moving objects

- **Face recognition** – identification of criminals, passport

Still More Applications

- **Robotics** – robot navigation, autonomous vehicles
- **Visualization** - real estate, site monitoring for surveillance
  - 3D reconstruction from a set of 2D images
  - Rendering – displaying the 3D object from different views
  - More…
- **Cell phones**
  - Very lossy compression, Small error Transmission, low power
- **Movies/Entertainment/Games…**
  - graphics (image synthesis), image analysis is the starting point to build models for synthesizing new images

Even More Applications

- **Video Conferencing**
  - Object oriented compression – MPEG 7
  - Requires object segmentation and tracking
- **Art/Archaeology** – restoring old paintings, writings
  - Image restoration, contrast enhancement
- **Remote sensing** – analyzing aerial imagery
- **Meteorology** – e.g. hurricanes, optical flow tracking, building models
- **Document Analysis** – e.g. handwriting recognition, digit recognition
- **VLSI testing** – defect analysis

Useful Background

- Probability & Statistics
- Signal Processing
- Linear Algebra
- Multivariable Calculus
- Good programming skills
  - C++/ Visual C++/Java – for industry
  - MATLAB – for graduate school
- **Image Processing class**
  - If you know some of above 5, very easy to pickup