

## Computational Photography CSC 290A

Summary, Some Important Concepts  
and Review Exercises

### September

#	Date	Topics
1	September Wed. 5	<b>Introduction</b> Course overview & history ( <a href="#">pdf of handouts</a> )
2	Mon.10	<b>Light and Image formation</b>
3	Wed.12	<b>Image sensors &amp; low level processing</b> <i>On the board:</i> (1) <i>Interpolating Polynomials</i> (2) <i>Cubic Spline Interpolation</i> New methods for extended Bayer patterns
4	Mon.17	<b>Color and perception</b> <i>On the board: More on cubic splines</i>
5	Wed.19	<i>On the board: Polynomial fitting, overdetermined systems and the normal equations</i> <b>High dynamic range imaging &amp; Tone Mapping</b> <i>On board: estimating non-linear functions</i>
6	Mon. 24	<b>Wavelets, pyramids and texture</b>
7	Wed.26	<b>Filtering, Image compression and</b> <a href="#">Assignment #1</a> hand out

### October

#	Date	Topics
	October Mon. 1	Traveling - Cornell. (Quiz)
8	Wed. 3	<b>Introduction to probability models</b> (blackboard only) • <i>Joint probability models vs. conditional models</i> • <i>Bayes' rule, marginalization and conditioning</i>
	Mon. 8	<i>Fall break</i>
9	Wed 10	<b>Probability models</b> part II (blackboard only) • <i>The chain rule and Bayesian networks</i> • <i>Conditional dependence and independence</i> • <i>Naive Bayes' models, MRFs &amp; linear classifiers</i>
10	Mon. 15	<b>Density estimation, clustering, classification and EM</b> <i>On the board:</i> • <i>Linear classifiers and Gaussian mixture models</i>
11	Wed. 17	<b>Factor graphs, the Sum Product Algorithm, Bayes' Nets and MRFs - Key idea 'computing marginals'</b>
12	Mon. 22	<i>On the board:</i> • <i>Clustering, k-means and the EM alg.</i> <b>Image segmentation and MRFs</b>

### Important Concepts in Probability

- The Fundamental Rule  $P(A, B) = P(A | B)P(B)$
- Bayes Rule  $P(B | A) = \frac{P(A | B)P(B)}{P(A)}$
- Marginalization  $P(x_i) = \sum_{x_{\setminus i}} P(x_1, x_2, \dots, x_N)$
- Conditioning  $P(A | B) = \frac{P(A, B)}{P(B)}$

### Questions / Suggested Exercises

Consider the following joint probability table for P(R,S,W).  
What is: P(R), P(R=T), P(R=T,W=T), P(R=T | W=T)?

Rained	Sprinkler	Wet Grass	Probability
T	T	T	.01
T	T	F	.00
T	F	T	.50
T	F	F	.05
F	T	T	.05
F	T	F	.01
F	F	T	.00
F	F	F	.38

### Questions - Probability Models

- Why are factorized probability models useful?
- What does a Bayesian Network represent?
- Could you draw the Bayesian Network for:  

$$P(\mathbf{x}, c) = P(x_1 | c)P(x_2 | c)P(c)$$

$$P(A, B, C) = P(B | C)P(C | A)P(A)$$

### Important Ideas – Two Classes of Probability Models

- Joint Probability Models
 
$$P(c, x) = P(x|c)P(c)$$
- Conditional Probability Models  
Where  $P(c|x)$  is modeled directly
 

e.g.

$$P(c|x) = \frac{\exp\left(\sum_{k=1}^K \lambda_k f_k(c, x)\right)}{\sum_c \exp\left(\sum_{k=1}^K \lambda_k f_k(c, x)\right)}$$

### Important Ideas – Graphical Descriptions

- Compare:
  - Bayesian Networks
  - Factor Graphs
- Why are these ideas useful?

### October

#	Date	Topics
13	October Wed. 24	<b>Image registration 1:</b> introduction - aerial, consumer, medical <ul style="list-style-type: none"> <li>Registration as a probabilistic graphical model</li> <li>Modeling complex deformations</li> </ul>
14	Mon. 29	<b>Image registration 2:</b> geometry, transformations and 3D <ul style="list-style-type: none"> <li>Coordinate systems</li> <li>Hierarchy of 2D transforms</li> <li>Cylindrical and spherical mappings</li> <li>Video stitching</li> </ul>
15	Wed. 31	<b>Image registration 3:</b> Medical image registration <ul style="list-style-type: none"> <li>Information theoretic methods</li> <li>Entropy of images</li> <li>Mutual information</li> <li>Combining with non-linear warping (skipped)</li> </ul>

### Important Ideas – Hierarchy of 2D Transforms

Name	Matrix	# D.O.F.	Preserves:	Icon
translation	$\begin{bmatrix} I & t \end{bmatrix}_{2 \times 3}$	2	orientation + ...	
rigid (Euclidean)	$\begin{bmatrix} R & t \end{bmatrix}_{2 \times 3}$	3	lengths + ...	
similarity	$\begin{bmatrix} sR & t \end{bmatrix}_{2 \times 3}$	4	angles + ...	
affine	$\begin{bmatrix} A \end{bmatrix}_{2 \times 3}$	6	parallelism + ...	
projective	$\begin{bmatrix} H \end{bmatrix}_{3 \times 3}$	8	straight lines	

- 2x3 matrices are extended with a row  $[0^T \ 1]$  to obtain 3x3 matrices for homogeneous coordinate transformations

- $$\begin{bmatrix} 1 & 0 & a \\ 0 & 1 & b \\ 0 & 0 & 1 \end{bmatrix}$$
  - Translation
- $$\begin{bmatrix} \cos \theta & -\sin \theta & a \\ \sin \theta & \cos \theta & b \\ 0 & 0 & 1 \end{bmatrix}$$
  - Euclidean
- $$\begin{bmatrix} a & -b & t_x \\ b & a & t_y \\ 0 & 0 & 1 \end{bmatrix}$$
  - Similarity
- $$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ 0 & 0 & 1 \end{bmatrix}$$
  - Affine
- $$\begin{bmatrix} a_{00} & a_{01} & a_{02} \\ a_{10} & a_{11} & a_{12} \\ a_{20} & a_{21} & a_{22} \end{bmatrix}$$
  - Homography

### Important Ideas – An Alternative Formulation of Affine Transformations

- Transformation parameters can be rewritten, gathering unknowns into  $\mathbf{x} = \{\mathbf{m}, \mathbf{t}\}$
- Further matches can be added, creating two additional rows to  $\mathbf{A}$  and  $\mathbf{b}$  for each match

$$\begin{bmatrix} x & y & 0 & 0 & 1 & 0 \\ 0 & 0 & x & y & 0 & 1 \\ \dots & & & & & \\ \dots & & & & & \end{bmatrix} \begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ m_4 \\ t_x \\ t_y \end{bmatrix} = \begin{bmatrix} u \\ v \\ \vdots \end{bmatrix}$$

$$\mathbf{Ax} = \mathbf{b} \quad \mathbf{x} = [\mathbf{A}^T \mathbf{A}]^{-1} \mathbf{A}^T \mathbf{b}$$

### November

#	Date		Topics
16	November	Mon. 5	<b>Dense stereo methods</b> <ul style="list-style-type: none"> <li>• Scanline matching</li> <li>• Dynamic programming</li> <li>• Markov random fields</li> <li>• Structured light to compute depth</li> </ul>
17		Wed. 7	<b>Saliency, Interest point detectors, Assignment #2 out</b> <ul style="list-style-type: none"> <li>• Entropy and scale</li> <li>• Scale space extrema, DoGs</li> </ul>
18		Mon. 12	<b>Feature descriptors I</b> <ul style="list-style-type: none"> <li>• Lowe's Scale Invariant Feature Transform (SIFT)</li> <li>• PCA and 'PCA SIFT'. <i>How do you use PCA?</i></li> </ul>
19		Wed. 14	<b>Feature descriptors II and Applications</b> <ul style="list-style-type: none"> <li>• Example: estimating affine transforms</li> <li>• Examples: finding objects</li> </ul>

### Important Ideas - Principal Component Analysis (PCA) & the Singular Value Decomposition SVD

$$\begin{matrix} \left[ \mathbf{X} \right] \\ t \times d \\ \text{rectangular} \end{matrix} = \begin{matrix} \left[ \mathbf{W} \right] \\ t \times k \\ \text{orthogonal} \\ \text{columns} \end{matrix} \begin{matrix} \begin{matrix} s_1 & & & \\ & s_2 & & \\ & & \ddots & \\ & & & s_k \end{matrix} \\ k \times k \\ \text{diagonal} \end{matrix} \begin{matrix} \left[ \mathbf{D}^T \right] \\ k \times d \\ \text{orthogonal} \\ \text{columns} \end{matrix}$$

- Stack up data as columns of matrix  $\mathbf{X}$
- Decompose into  $\mathbf{X} = \mathbf{WSD}^T$

### November

#	Date		Topics
20	November	Mon. 19	<b>Object recognition I</b> <ul style="list-style-type: none"> <li>• Vocabulary trees</li> <li>• Text retrieval based approaches</li> </ul>
		Wed. 21	Thanksgiving break
21		Mon. 26	<b>Object recognition II &amp; Bundle Adjustment</b> <ul style="list-style-type: none"> <li>• Objects vs. object categories</li> <li>• CalTech 101, 256</li> <li>• 80 Million Tiny Images</li> <li>• Constellation models</li> </ul>
22		Wed. 28	<b>Face detection and recognition (Assignment #2 due)</b> <ul style="list-style-type: none"> <li>• Names and faces in the news</li> <li>• Combining text information and visual information</li> </ul>

### December

#	Date		Topics
23	Dec.	Mon. 3	<b>Features and video processing</b> <ul style="list-style-type: none"> <li>• Optical flow (Lucas and Kanade)</li> <li>• Video features and tracking</li> <li>• Bundle adjustment</li> </ul>
24		Wed. 5	<b>Project presentations</b> (15min talk, 5min questions) 1) Corey Proscia, Wavelets & Applications 2) Kyle Sabo, The Fourier Transform & Applications 3) Matthew Leventi, Viewing Large Images
25		Mon. 10	<b>Project presentations</b> (15min talk, 5min questions) 4) Stephan Delmer, Automated Stitching 5) Mark Washburn, Face Detection 6) Nicholas Sedney, Colorization or Matting
26		Wed. 12	7) Sean Lander, The Radon Transform Wrap up, summary and recommended exercises. <b>Reminder EXAM is: Mon, Dec. 17, 3:25-4:40 CSB 601</b>