CSC320H: Intro to Visual Computing

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Course WWW (course information sheet available there):
http://www.cs.toronto.edu/~mangas/teaching/320

Textbooks:
- Digital Image Processing,
- OpenGL Programming Guide
  (both recommended but not required)

Tutorials: Wednesdays at 8 pm (first tutorial next week)

Fernando is...

He apologizes and will be here next week.
Today’s Topics

0. Admin stuff

1. Intro to Visual Computing

2. Image formation process and high dynamic range photography

Admin stuff

- Bulletin board (running!):

  https://piazza.com/utoronto.ca/winter2014/csc320/home
  link available from course website

- Grading
  40%: four assignments, worth 10% each, due at 11:59pm on due date.
  20%: one midterm test, in tutorial
  40%: one final exam

  See calendar on course website for dates and other details.
Admin stuff

• A1 out this Friday via course website
  – Due Jan 24!
  – A1 cannot be done last-minute. Things will go wrong.
    • Read course Info-Sheet for “late policy”
    • While at it, check other assignment-related policies (especially on academic honesty)

• Tutorials:
  – Math refreshers and visual programming.
  – Attendance is STRONGLY encouraged.
  – Visual programming or assignments will be discussed in the tutorials ONLY, not in class.

• First tutorial is next Wednesday (Jan 15)
  – Intro to programming toolkits (useful for A1)
    • fluid, fltk, VXL
  – Refresher on solving linear systems of equations

• Lecture notes: on course website, after class.
Topic 0

• Intro to Visual Computing
  – What is visual computing?
  – Is this course for me?
  – Course topics
What visual computing is NOT

• How do I use Adobe Photoshop© to...

From http://hollywoodactressbeforephotoshop.blogspot.mx/

What visual computing is NOT

• The ultimate gaming video card is...

Nvidia GeForce GTX 690

$1059.14

Pros
The GTX 690 is the fastest graphics card available. It has dual GPUs, extremely high memory bandwidth and great power efficiency.

Cons
The card is very long, and because there is no native HDMI connection, you have to use a displayport dongle.

The Verdict: 9.98/10
The GTX 690 gives unparalleled speed and quality to your gaming experience, easily running games on high and ultra settings without breaking a sweat.

What visual computing actually is!

- To use (mainly) geometry- and physics-based models to generate images that mean something to people

- Other disciplines used (and abused)
  - Mathematics
  - Optics
  - Computer Science
  - Engineering
  - Psychophysics
  - Visual Arts

From http://www.disneyanimation.com/technology/publications#
By Stomakhin, et al. at Disney Animation Studios

Objective #1: Realistic Image Synthesis

- Create pictures and videos that convey the illusion of reality

(Ramamoorthy et al, SIGGRAPH'01)
Objective #2: Capturing Reality

• Example: Capturing real scenes in museums, etc

(Levoy et al, SIGGRAPH’00)
http://graphics.stanford.edu/projects/mich

Objective #3: Manipulating Photos and Videos

• Manipulate reality (e.g. for special effects)

http://www.thepixelart.com/
Objective #3: Manipulating Photos and Videos

- Manipulate reality (e.g. for special effects)

Seitz & Dyer, SIGGRAPH’96

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Objective #4: Photo and Video Interpretation

- Detection, tracking

Shu, Dehghan, Oreifej, Hand, Shah. CVPR 2012

(El-Maraghi et al, CVPR’01)

(Rowley et al, PAMI’98)
Objective #4: Photo and Video Interpretation

e.g. Face recognition (in Google’s Picassa)

Objective #4: Photo and Video Interpretation

e.g. Automatic object & location recognition with Google Goggles
Topic 0

• Intro to Visual Computing

– What is visual computing?
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Is this course for me?

Visual Computing
• Application of the rules of math and physics to generate images that mean something to people

• You must be comfortable with
  – Linear algebra
  – Elementary calculus

• You must be willing to code... a lot!

By Stomakhin, et al. at Disney Animation Studios
Assignment 1: Demo

What you will take away

1. Math drives CS
2. How to use math to create pictures
3. Basics on Image manipulation
4. Intro to coding interactive tools
5. How to read research papers
Where does this course fit?

- 320 has some thematic overlap with 418 or 2503, BUT the underlying math is the same (i.e. taking 320 first will most definitely help!)

Where does this course fit?

At the intersection of computer vision and computer graphics because often real photos are the input!

- Video examples
  - Slavenly et al, SIGGRAPH 06
    • Phototourism: Organizing photo collections in 3D
Phototurism

Photo Tourism
Exploring photo collections in 3D

Noah Snavely  Steven M. Seitz  Richard Szeliski
University of Washington  Microsoft Research

SIGGRAPH 2006

Topic 0

• Intro to Visual Computing

  – What is visual computing?
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Course Topics

• Principles
  – Computational and mathematical principles for creating, capturing, analyzing and manipulating 2D photos

• Case Studies
  – Applying these principles to the design of specific image manipulation tools (mostly for special effects)

• Visual Programming and Numerical Computing (in tutorials)
  – Learning to use software tools and C++ libraries for graphical user interface design.
  – Implementing math operations on images

Visual Computing Principles

• Imaging essentials (~2 weeks)
  – Understanding pixel intensity and color

• Image representation and transformation
  – Image ⇔ 2D array of pixels
  – Image ⇔ continuous 2D function (4 weeks)
  – Image ⇔ N-Dimensional vector (2.5 weeks)
  – Hierarchical image representations (2 weeks)
  – Image matching and transformation (3 weeks)
Visual Programming

- Basic tools we will use
  - FLUID and fltk GUI toolkit (by Digital Domain)
  - VXL library for image analysis and numerical computing (by a major consortium of computer vision researchers)

- All these tools are under GNU license and are completely portable (Linux/Windows/OSX)

Topic 1
Image Formation and High Dynamic Range (HDR) Photography

- Imaging sensors (in grayscale)
- High Dynamic Range photography
- Digital image formation
- The camera response function
- Computing the camera response function
The Digital Single-Lens Reflex Camera

From http://www.digishop.org/

The Imaging Sensor

- An array of photo-sensitive cells (usually 2-dimensional), each corresponding to one pixel (picture element)

- Light falling onto a cell induces voltage that depends on the intensity of the incident light

- Voltage is the converted to a digital signal within a sensor specific range (in a 8-, 10- or 14-bit number)
The Imaging Sensor

- An array of photo-sensitive cells (usually 2-dimensional), each corresponding to one pixel (*picture element*)

- Light falling onto a cell induces voltage that depends on the intensity of the incident light
- Voltage is the converted to a digital signal within a sensor specific range (in a 8-, 10- or 14-bit number)

What does the value of a pixel mean?

- Pixel values in an image are clearly related to the amount of incoming light, but how exactly?

- And crucially, why do we care about this relation?
The Imaging Sensor

- An array of photo-sensible cells (usually 2-dimensional), each corresponding to one pixel (picture element).

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- Voltage is the converted to a digital signal within a sensor specific range (in a 8-, 10- or 14-bit number).

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Topic 1

Image Formation and High Dynamic Range (HDR) Photography

- Imaging sensors (in grayscale)
- High Dynamic Range photography
- Digital image formation
- The camera response function
- Computing the camera response function
One major difficulty in photography

Scenes with very bright and very dark areas are hard to capture

Long- and short-exposure photos (Debevec et al, SIGGRAPH’97)

High-Dynamic Range Photography

• See flickr.com for many examples
High-Dynamic Range Photography

The 8-bit values at each pixel in all photos are converted to a single floating point value.

To do this, we must know how the sensor cells convert light to 8-bit values. Why?
High-Dynamic Range Photography

• Question:
  – Suppose we take two photos A and B with exposure intervals $\Delta t$ and $\frac{1}{2}\Delta t$. The intensity at pixel $(x,y)$ will satisfy:

  • a) $A(x,y) = 2 \ B(x,y)$
  • b) $A(x,y) = \frac{1}{2} B(x,y)$
  • c) $A(x,y) = B(x,y)$
  • d) none of the above

High-Dynamic Range Photography

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  • b) $A(x,y) = \frac{1}{2} B(x,y)$
  • c) $A(x,y) = B(x,y)$
  • d) none of the above (most likely!)
Topic 1

Image Formation and High Dynamic Range (HDR) Photography

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Digital Image Formation: Basic Steps

Adapted from Debevec et al, SIGGRAPH 97
Digital Image Formation: Basic Steps

Adapted from Debevec et al, SIGGRAPH 97

Photons/sec received at the cell

Adapted from Debevec et al, SIGGRAPH 97
Digital Image Formation: Basic Steps

Photons/sec received at the cell
Total photos received at cell during exposure time ($\Delta t$)

The Camera response function $f$
$Z = f(E \Delta t)$

Adapted from Debevec et al, SIGGRAPH 97
Digital Image Formation: Basic Steps

The Camera response function $f$

$Z = f(E \Delta t)$

Pixel value

Irradiance

Exposure time

Adapted from Debevec et al, SIGGRAPH 97

Topic 1

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Example Camera Response Functions

From Grossberg & Nayar, CVPR 2003
Application: High-Dynamic Range Photography

Captured photos

30 s  20 s  10 s

Merged HDR Photos

1/100 s  1/500 s  1/1000 s

Basic merging procedure:

For each pixel (x,y)
For each photo j
  if (x,y) is not saturated in j
    Convert pixel intensity $Z_j(x,y)$ to linear irradiance measurement $E_j(x,y)$

Merge $E_1(x,y)$, $E_2(x,y)$,... into one floating point value
High-Dynamic Range Photography

Computing Response functions and HDR photos

Hacked camera firmware for Canon Powershots

Topic 1

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Computing The Camera Response Function

**General Procedure:**
1. Collect photos for several exposure intervals $\Delta t_1, \Delta t_2, \ldots$ without moving the camera
2. Process photos to compute $f$

**Problem:**
For a given photo we know $\Delta t_j$ and $Z$ but we have no way of measuring $E$

**Idea #1:** Invert and use logs

$$Z = f(E \Delta t)$$

$$f^{-1}(Z) = E \Delta t$$

$$\log f^{-1}(Z) = \log(E) + \log(\Delta t)$$

**Log-Inverse response fn:**
$$g(Z) = \log(E) + \log(\Delta t)$$
Computing The Camera Response Function

Idea #2: How many quantities must we observe to fully determine $g()$?

Ans: 256 ($g(0), g(1), ..., g(256)$)
Computing The Camera Response Function

Approach #1: One pixel, many images

1. Finely adjust $\Delta t$ in range (1/1000s, 30 s)
2. Plot $\log \Delta t$ as a function of the pixels’ observed intensity.

But $\log E$ is unknown! Does it matter?
Computing The Camera Response Function

Approach #1: One pixel, many images
- What are the problems with this approach?
  - Need lots of images
  - Wasted pixels (we use only one out of thousands in the photo)
  - Possible $\Delta t$ values are often determined by the camera

The log-inverse response function

Computing The Camera Response Function

Approach #2: Few pixels, few images?
- $g(Z) = \log E + \log \Delta t$
- Same for all pixels
- Sample for all pixels in a photo

Samples of $g(Z)$ for multiple pixels and photos
Computing The Camera Response Function

Approach #2: Few pixels, few images?

To compute the complete function we must estimate the relative vertical shift of the $g(Z)$ function from individual pixels.

Samples of $g(Z)$ for multiple pixels and photos.

- Observed intensity (known)
- Exposure interval (known)
- i\textsuperscript{th} pixel
- j\textsuperscript{th} image
- Irradiance of i\textsuperscript{th} pixel (unknown)

Goal:
Compute $g(0), g(1), ..., g(255)$ and $\log E_i$
Given N pixel intensities in P images with known $\Delta t_j$
Computing The Camera Response Function

Simplifying the notation: \( g(Z_{ij}) = \log E_i + \log \Delta t_j \)

becomes

\[ gZ_{ij} - e_i = \delta_j \]

Example: Pixel 100 in the 5th photo has intensity 125, denoted as \( Z_{100,5} = 125 \). The associated equation is:

\[ g_{125} - e_{100} = \delta_5 \]

Computing The Camera Response Function

Approach #2: Few pixels, few images?

\( g(Z_{ij}) = \log E_i + \log \Delta t_j \)

We know the above equation is true for all pixels and for all images.

This means we have N\(\cdot\)P equations with N+256 unknowns (one equation per pixel per photo)