University of British Columbia
CPSC 314 Computer Graphics
May-June 2005

Tamara Munzner

Animation, Advanced Rendering, Final Review

Week 6, Tue Jun 14

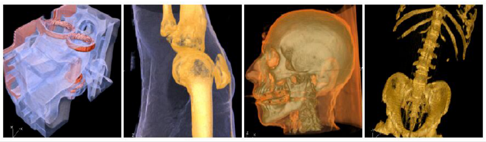
http://www.ugrad.cs.ubc.ca/~cs314/Vmay2005

News

- P4 grading
  - 4:30-5:45 Wed Jun 22

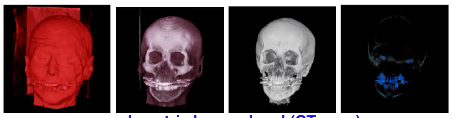
Review: Volume Graphics

- for some data, difficult to create polygonal mesh
- voxels: discrete representation of 3D object
  - volume rendering: create 2D image from 3D object
- translate raw densities into colors and transparencies
  - different aspects of the dataset can be emphasized via changes in transfer functions



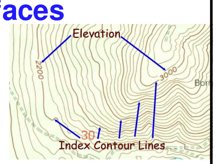
Review: Volume Graphics

- pros
  - formidable technique for data exploration
- cons
  - rendering algorithm has high complexity!
  - special purpose hardware costly (~$3K-$10K)

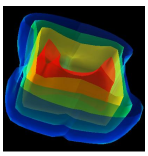


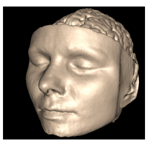
volumetric human head (CT scan)

Review: Isosurfaces



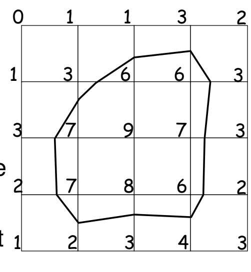
- 2D scalar fields: isolines
  - contour plots, level sets
  - topographic maps
- 3D scalar fields: isosurfaces





Review: Isosurface Extraction

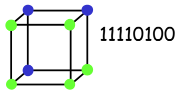
- array of discrete point samples at grid points
  - 3D array: voxels
- find contours
  - closed, continuous
  - determined by iso-value
- several methods
  - marching cubes is most common

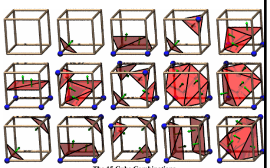


Iso-value = 5

Review: Marching Cubes

- create cube
- classify each voxel
- binary labeling of each voxel to create index
- use in array storing edge list
  - all 256 cases can be derived from 15 base cases
- interpolate triangle vertex
- calculate the normal at each cube vertex
- render by standard methods



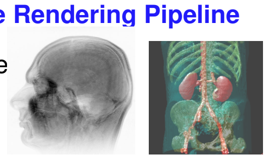


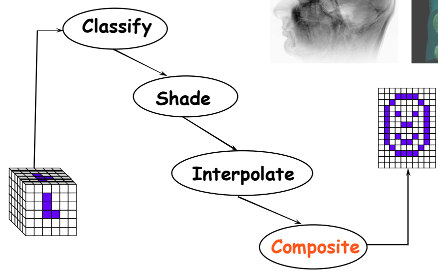
The 15 Cube Combinations

7

Review: Direct Volume Rendering Pipeline

- do not compute surface

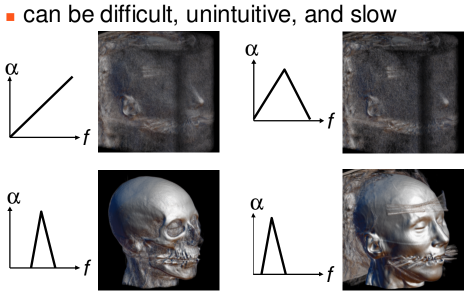




8

Review: Transfer Functions To Classify

- map data value to color and opacity
  - can be difficult, unintuitive, and slow

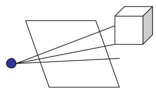


Gordon Kindlmann

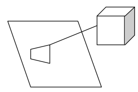
9

Review: Volume Rendering Algorithms

- ray casting
  - image order, forward viewing



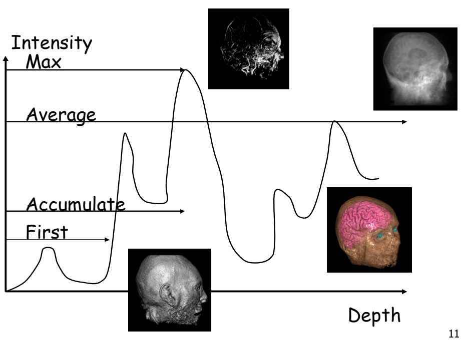
- splatting
  - object order, backward viewing



- texture mapping
  - object order
  - back-to-front compositing

10

Review: Ray Casting Traversal Schemes



11

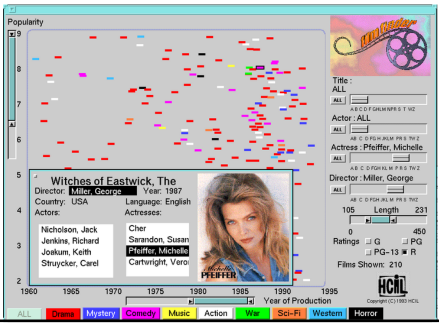
Review: Information Visualization

- interactive visual representation of abstract data
  - help human perform some task more effectively
- bridging many fields
  - graphics: interacting in realtime
  - cognitive psych: finding appropriate representation
  - HCI: using task to guide design and evaluation
- external representation
  - reduces load on working memory
  - offload cognition
- familiar example: multiplication/division
- infovis example: topic graphs

12

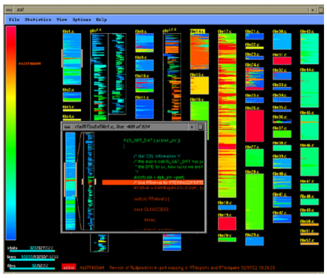
Review: Shneiderman mantra

- overview, zoom and filter, details-on-demand



Review: Overviews - SeeSoft

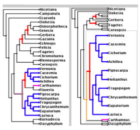
- colored lines of code: lines one pixel high



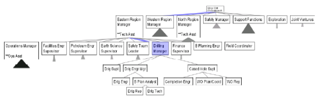
Review: Focus+Context

- integrate overview and details into single view
  - H3: 3D fisheye

  - TreeJuxtaposer: stretch and squish

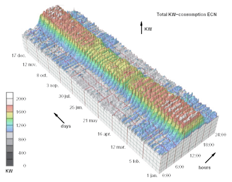


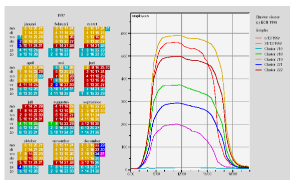
  - SpaceTree: collapse/expand



Review: 3D Extrusion vs. Linking

- perspective interferes with comparison
  - daily, weekly patterns hard to see
- linked cluster/calendar view more effective

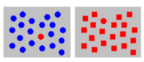




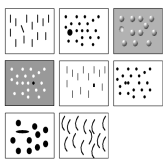
[van Wijk and van Selow, Cluster and Calendar based Visualization of Time Series Data, InfoVis99, citeseer.nj.nec.com/vanwijk99cluster.html]

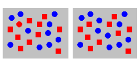
Review: Preattentive Visual Channels: Popout

- single channel processed in parallel for popout
  - visual attentional system not invoked
  - speed independent of distractor count



  - hue, shape, texture, length, width, size, orientation, curvature, intersection, intensity, flicker, direction of motion, stereoscopic depth, lighting direction,...
- multiple channels not parallel
  - search linear in number of distractor objects





[Chris Healey, Preattentive Processing, www.csc.ncsu.edu/faculty/healey/PP]

Review: Data Type Affects Channel Ranking

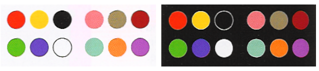
- spatial position best for all types
  - accuracy at judging magnitudes, from best to worst

Quantitative	Ordinal	Nominal
Position	Position	Position
Length	Density	Hue
Angle	Saturation	Texture
Slope	Hue	Connection
Area	Texture	Containment
Volume	Connection	Density
Density	Containment	Saturation
Saturation	Length	Shape
Hue	Angle	Length
Texture	Slope	Angle
Connection	Area	Slope
Containment	Volume	Area
Shape	Shape	Volume

[Mackinlay, Automating the Design of Graphical Presentations of Relational Information, ACM TOG 5:2, 1986]
[Card, Mackinlay, and Shneiderman. Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann 1999. Chapter 1]

Review: Coloring Categorical Data

- discrete small patches separated in space
- limited distinguishability: around 8-14
  - channel dynamic range: low
  - choose bins explicitly for maximum mileage
- maximally discriminable colors from Ware
  - maximal saturation for small areas
    - vs. minimal saturation for large areas

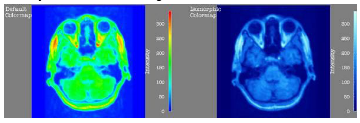


[Colin Ware, Information Visualization: Perception for Design. Morgan Kaufmann 1999. Figure 4.21]

19

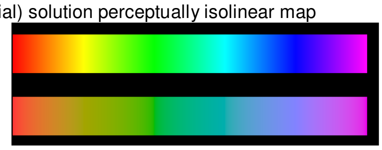
Review: Rainbow Colormap Disadvantages

- perceptually nonlinear segmentation, hue unordered



[Rogowitz and Treinish, How NOT to Lie with Visualization,www.research.ibm.com/dx/proceedings/pravda/truevis.htm

- (partial) solution perceptually isolinear map



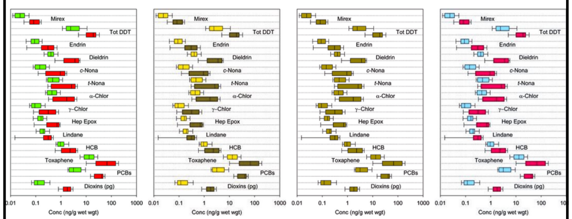
[Kindlmann, Reinhard, and Creem. Face-based Luminance Matching for Perceptual Colormap Generation. Proc. Vis 02 www.cs.utah.edu/~gk/lumFace]

20

Review: Color Deficiency – vischeck.com

- 10% of males have red/green deficit

original protanope deuteranope tritanope

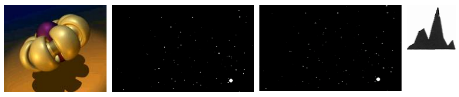


[www.cs.ubc.ca/~tmm/courses/cpsc533c-04-spr/a1/dmitry/533a1.html, citing Global Assessment of Organic Contaminants in Farmed Salmon, Ronald A. Hites, Jeffery A. Foran, David O. Carpenter, M. Coreen Hamilton, Barbara A. Knuth, and Steven J. Schwager, Science 2004 303: 226-229.]

Review: Space vs. Time: Showing Change

literal abstract
<--->
time for time space for time

animation: show time using temporal change
- good: show process
- good: compare by flipping between two things
- bad: compare between many things
  interference from intermediate frames

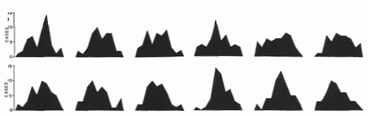


[Outside In excerpt. www.geom.uiuc.edu/docs/outreach/oi/evert.mpg]
[www.astroshow.com/ccdpho/pluto.gif]
[Edward Tufte. The Visual Display of Quantitative Information, p 172]

Review: Space vs. Time: Showing Change

literal abstract
<--->
time for time space for time

small multiples: show time using space
- overview: show each time step in array
- compare: side-by-side easier than temporal
  external cognition instead of internal memory
- general technique, not just for temporal changes



[Edward Tufte. The Visual Display of Quantitative Information, p 172]

Animation

(slides based on Robert Bridson's CPSC 426 preview)
www.ugrad.cs.ubc.ca/~cs426

24

Computer Animation

- offline: generate a film, play it back later
- long ago reached the point of being able to render anything an artist could model
- problem is: how to model?
  - tools/UI for directly specifying model+motion (the traditional technique)
  - procedural modeling (e.g. particle systems)
  - data-driven modeling (e.g. motion capture)
  - physics-based modeling (e.g. fluid simulation)

25

Real-Time Animation

- for example, games
- rendering limited, modeling even more limited
- “traditional” technique - replay scripted motions
  - but scalability/realism are becoming a problem
  - need to generate more new motion on the fly

26

Traditional CG Animation

- Grew out of traditional animation
- [Pixar]
- every detail of every model is parameterized
  - e.g. position and orientation of base of lamp, joint angles, lengths, light intensity, control points for spline curve of power cord, …
- associate a “motion curve” with each parameter - how it changes in time
- animating == designing motion curves

27

Motion Curves

- keyframe approach:
  - artist sets extreme values at important frames
  - computer fills in the rest with splines
  - artist adjusts spline controls, slopes, adds more points, adjusts, readjusts, re-readjusts, …
- straight-ahead approach:
  - artist simply sets parameters in each successive frame
- layering approach:
  - design the basic motion curves first, layer detail on afterwards

28

Motion Curve Tools

- retiming: keep the shape of the trajectory, but change how fast we go along it
  - add a new abstract motion curve controlling distance traveled along trajectory
- Inverse Kinematics (IK):
  - given a skeleton (specified by joint angles)
  - artist directly controls where parts of the skeleton go, computer solves for the angles that achieve that

29

Procedural Modeling

- write programs to automatically generate models and motion
- for example, “flocking behaviour”
- build a flock of birds by specifying simple rules of motion:
  - accelerate to avoid collisions
  - accelerate to fly at preferred distance to nearby birds
  - accelerate to fly at same velocity as nearby birds
  - accelerate to follow “migratory” impulse
- let it go, hope the results look good

30

Data-Driven Modeling

- measure the real world, use that data to synthesize models
  - laser scanners
  - camera systems for measuring reflectance properties
  - Image-Based Rendering - e.g. Spiderman
  - …

31

Data-Driven Motion

- record real motion (motion capture = mocap)
- then play it back
- but life is never that simple
  - real motion is hard to measure
  - measurements are noisy
  - won't quite fit what you needed
  - not obviously adaptable to new environments, interactive control, etc.

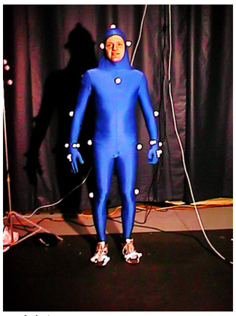
32

Marker-Based Mocap

- stick performer in a tight black suit, stick markers on body, limbs, …
- film motion with an infrared strobe light and multiple calibrated cameras
- reconstruct 3D trajectories of markers, filling in gaps and eliminating noise
- infer motion of abstract skeleton
- clean up data
- drive CG skeleton with recorded motion curves

33

What it looks like…



(from Zoran Popovic's website)

34

Footskate and Clean Up

- most common problem: footskate
  - feet that in reality were stuck to floor hover and slip around
- fix using IK: determine target footplants, automatically adjust joint angles to keep feet planted
  - often OK to even adjust limb lengths…

35

Motion Control

- how do you adapt mocap data to new purposes?
  - motion graphs (remixing)
  - motion parameterization (adjust mocap data)
  - motion texturing (add mocap details to traditional animation)

36

Motion Graphs

- chop up recorded data into tiny clips
  - aim to cut at common poses
- build graph on clips: connect two clips if the end pose of one is similar to the start pose of another
- then walk the graph
  - figure out smooth transitions from clip to clip
  - navigate a small finite graph instead of infinite space of all possible motions

37

Physics-based modeling

- like procedural modeling, only based on laws of physics
- if you want realistic motion, simulate reality
- human motion:
  - specify muscle forces (joint torques), simulate actual motion
  - has to conserve momentum etc.
  - can handle the unexpected (e.g. a tackle)
  - but need to write motion controllers
- passive motion:
  - figure out physical laws behind natural phenomena
  - simulate (close cousin of scientific computing)

38

Advanced Rendering

39

Reading

- FCG Chapter 9: Ray Tracing
  - only 9.1-9.7
- FCG Chap 22: Image-Based Rendering

40

Errata

- p 155
  - line 1: p(t)=e+td, not p(t)=o+td
  - equation 5: 2nd term 2d*(e-c), not 2d*(o-e)
- p 157
  - matrices: c_x->x_c, c_y->y_c, c_z->z_c
- p 162
  - r = d – 2(d.n)n, not r = d + 2(d.n)n
- p 163
  - eqn 4 last term: n cos θ not n cos θ '
  - eqn 5: no θ term at end

41

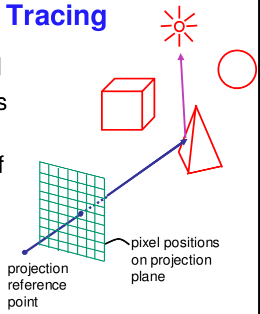
Global Illumination Models

- simple shading methods simulate local illumination models
  - no object-object interaction
- global illumination models
  - more realism, more computation
- approaches
  - ray tracing
  - subsurface scattering
  - radiosity

42

Simple Ray Tracing

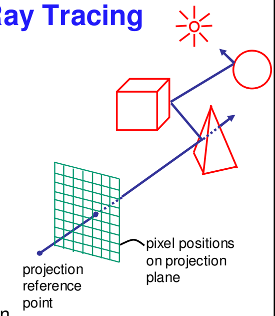
- view dependent method
  - cast a ray from viewer's eye through each pixel
  - compute intersection of ray with first object in scene
  - cast ray from intersection point on object to light sources



43

Recursive Ray Tracing

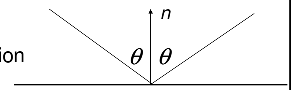
- ray tracing can handle
  - reflection (chrome)
  - refraction (glass)
  - shadows
- spawn secondary rays
  - reflection, refraction
    - if another object is hit, recurse to find its color
  - shadow
    - cast ray from intersection point to light source, check if intersects another object

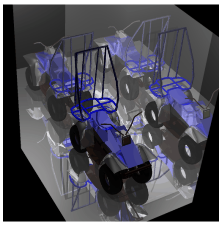


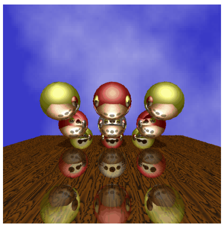
44

Reflection

- mirror effects
  - perfect specular reflection



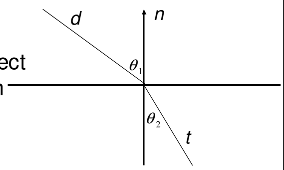


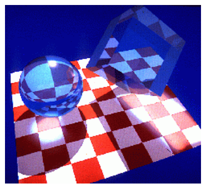


45

Refraction

- happens at interface between transparent object and surrounding medium
  - e.g. glass/air boundary
- Snell's Law
  - $c_1 \sin\theta_1 = c_2 \sin\theta_2$
  - light ray bends based on refractive indices c_1, c_2

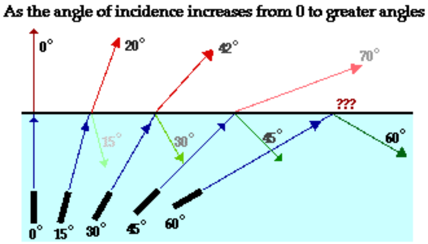




46

Total Internal Reflection

As the angle of incidence increases from 0 to greater angles ...

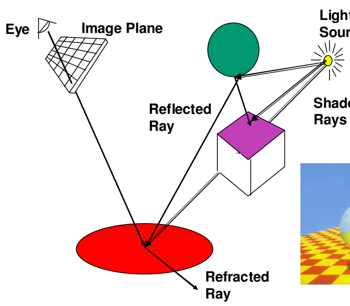


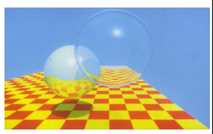
...the refracted ray becomes dimmer (there is less refraction)
...the reflected ray becomes brighter (there is more reflection)
...the angle of refraction approaches 90 degrees until finally a refracted ray can no longer be seen.

http://www.physicsclassroom.com/Class/refrn/U14L3b.html

47

Ray Tracing Algorithm





Whitted, 1980

48

Basic Ray Tracing Algorithm

```
RayTrace(r,scene)
obj := FirstIntersection(r,scene)
if (no obj)  return BackgroundColor;
else begin
   if ( Reflect(obj) ) then
      reflect_color := RayTrace(ReflectRay(r,obj));
   else
      reflect_color := Black;
  if ( Transparent(obj) ) then
      refract_color := RayTrace(RefractRay(r,obj));
   else
      refract_color := Black;
  return Shade(reflect_color,refract_color,obj);
end;
```

49

Algorithm Termination Criteria

- termination criteria
  - no intersection
  - reach maximal depth
    - number of bounces
  - contribution of secondary ray attenuated below threshold
    - each reflection/refraction attenuates ray

50

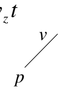
Ray - Object Intersections

- inner loop of ray-tracing
  - must be extremely efficient
- solve a set of equations
  - ray-sphere
  - ray-triangle
  - ray-polygon

51

Ray - Sphere Intersection

- ray: $x(t) = p_x + v_x t,\ \ y(t) = p_y + v_y t,\ \ z(t) = p_z + v_z t$



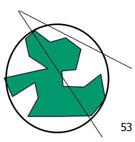
- unit sphere: $x^2 + y^2 + z^2 = 1$
- quadratic equation in t:

$$
\begin{aligned}
0 &= (p_x + v_x t)^2 + (p_y + v_y t)^2 + (p_z + v_z t)^2 - 1 \\
&= t^2 (v_x^2 + v_y^2 + v_z^2) + 2t(p_x v_x + p_y v_y + p_z v_z) \\
&\quad + (p_x^2 + p_y^2 + p_z^2) - 1
\end{aligned}
$$

52

Optimized Ray-Tracing

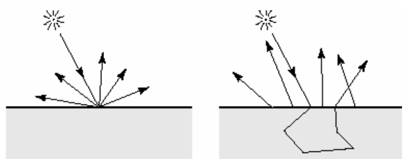
- basic algorithm simple but very expensive
- optimize by reducing:
  - number of rays traced
  - number of ray-object intersection calculations
- methods
  - bounding volumes: boxes, spheres
  - spatial subdivision
    - uniform
    - BSP trees
- (not required reading)



53

Subsurface Scattering: Translucency

- light enters and leaves at *different* locations on the surface
  - bounces around inside
- technical Academy Award, 2003
  - Jensen, Marschner, Hanrahan



54

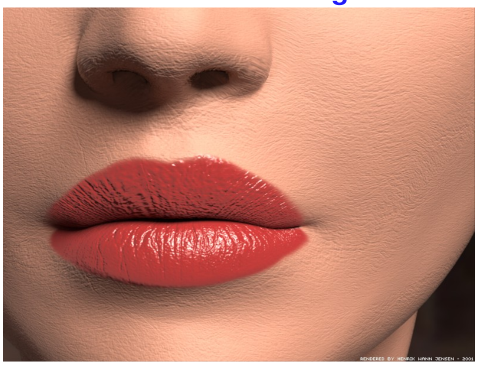
Subsurface Scattering: Marble

55

Subsurface Scattering: Milk vs. Paint

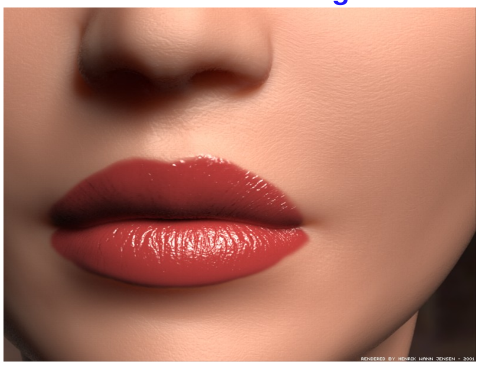
56

Subsurface Scattering: Faces



57

Subsurface Scattering: Faces



58

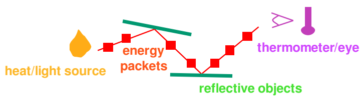
Radiosity

- radiosity definition
  - rate at which energy emitted or reflected by a surface
- radiosity methods
  - capture diffuse-diffuse bouncing of light
    - indirect effects difficult to handle with raytracing

59

Radiosity

- recall radiative heat transfer



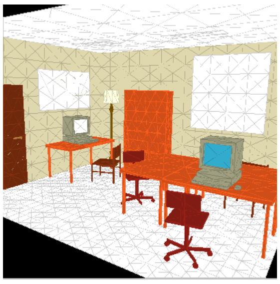
  - conserve light energy in a volume
  - model light transport until convergence
  - solution captures diffuse-diffuse bouncing of light

- view independent technique
  - calculate solution for entire scene offline
  - browse from any viewpoint in realtime

60

Radiosity

- divide surfaces into small patches
- loop: check for light exchange between all pairs
  - form factor: orientation of one patch wrt other patch (n x n matrix)

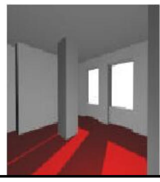


61

Raytracing vs. Radiosity Comparison

- ray-tracing: great specular, approx. diffuse
  - view dependent
- radiosity: great diffuse, specular ignored
  - view independent, mostly-enclosed volumes
- advanced hybrids: combine them

raytraced

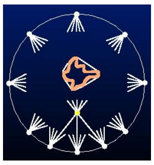


radiosity

62

Image-Based Rendering

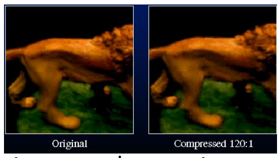
- store and access only pixels
  - no geometry, no light simulation, ...
  - input: set of images
  - output: image from new viewpoint
    - surprisingly large set of possible new viewpoints



63

IBR Characteristics

- display time not tied to scene complexity
  - expensive rendering or real photographs
- massive compression possible (120:1)



- can point camera in or out
  - QuickTimeVR: camera rotates, no translation

64

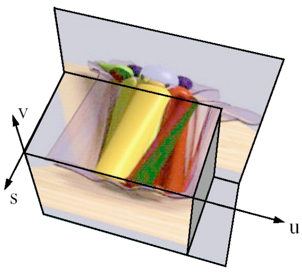
Characterizing Light

- 7D plenoptic function: P(x, y, z, θ, φ, λ, t)
  - (x,y,z): every position in space
  - (θ, φ): every angle
  - λ: every wavelength of light
  - t: every time
- can simplify to 4D function
  - fix time: static scene
  - fix wavelength: static lighting
  - partially fix position: empty space between camera and object

65

4D Light Field / Lumigraph

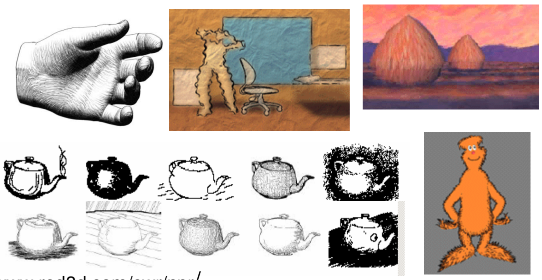
- P(u,v,s,t)
  - images: just one kind of 2D slice



66

Non-Photorealistic Rendering

- look of hand-drawn sketches or paintings



www.red3d.com/cwr/npr/

67

NPRQuake

www.cs.wisc.edu/graphics/Gallery/NPRQuake

68

Advanced Rendering

- so many more algorithms, so little class time!
  - Renderman REYES
  - photon mapping
  - and lots more...

69

Final Review

70

Final Logistics

- 12:0pm-2:30pm Thu Jun 16 here (MCLD 202)
- notes: both sides 8.5”x11” handwritten page
- calculator OK if you want
- have photo ID face up on desk
- spread out, sit where there is an exam

71

Reading from OpenGL Red Book

- 1: Introduction to OpenGL
- 2: State Management and Drawing Geometric Objects
- 3: Viewing
- 4: Display Lists
- 6: Lighting
- 9: Texture Mapping
- 12: Selection and Feedback
- 13: Now That You Know
  - only section Object Selection Using the Back Buffer
- Appendix: Basics of GLUT (Aux in v 1.1)
- Appendix: Homogeneous Coordinates and Transformation Matrices

72

Reading from Shirley: Foundations of CG

- 2: Misc Math
- 3: Raster Algs
  - except for 3.8
- 4: Linear Algebra
  - only 4.1-4.2.5
- 5: Transforms
  - except 5.1.6
- 6: Viewing
- 7: Hidden Surfaces
- 8: Surface Shading
- 9: Ray Tracing
  - only 9.1-9.7
- 10: Texture Mapping
- 11: Graphics Pipeline
  - only 11.1-11.4
- 12: Data Structures
  - only 12.3
- 13: Curves and Surfaces
- 17: Human Vision
- 18: Color
  - only 18.1-18.8
- 22: Image-Based Rendering
- 23: Visualization

73

Studying Advice

- do problems!
  - work through old homeworks, exams

74

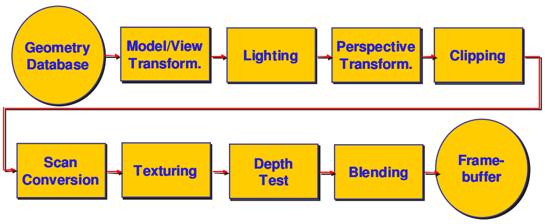
Midterm Topics Covered

- rendering pipeline
- projective rendering pipeline
  - coordinate systems
- transformations
- viewing
- projections

75

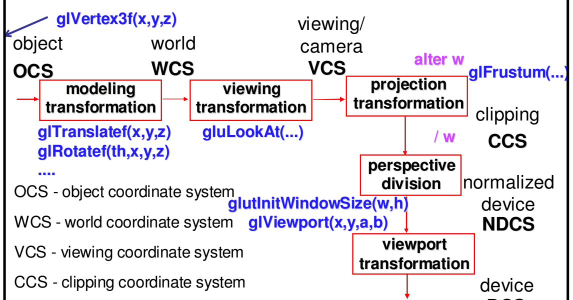
Review: Rendering Pipeline

- pros and cons of pipeline approach



76

Review: Projective Rendering Pipeline



OCS - object coordinate system

WCS - world coordinate system

VCS - viewing coordinate system

CCS - clipping coordinate system

NDCS - normalized device coordinate system

DCS - device coordinate system

77

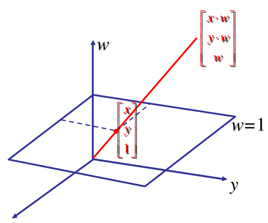
Review: Transformations, Homog. Coords

translate(a,b,c)

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & & & a \\ & 1 & & b \\ & & 1 & c \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

scale(a,b,c)

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a & & & \\ & b & & \\ & & c & \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$



$\mathrm{Rotate}(x, \theta)$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & & & \\ & \cos\theta & -\sin\theta & \\ & \sin\theta & \cos\theta & \\ & & & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$\mathrm{Rotate}(y, \theta)$

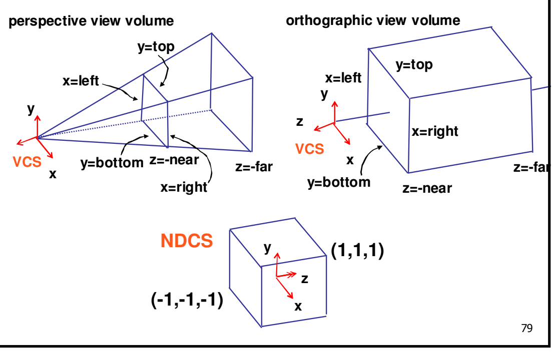
$$\begin{bmatrix} \cos\theta & & \sin\theta & \\ & 1 & & \\ -\sin\theta & & \cos\theta & \\ & & & 1 \end{bmatrix}$$

$\mathrm{Rotate}(z, \theta)$

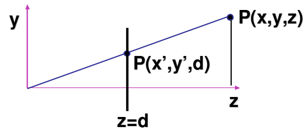
$$\begin{bmatrix} \cos\theta & -\sin\theta & & \\ \sin\theta & \cos\theta & & \\ & & 1 & \\ & & & 1 \end{bmatrix}$$

78

Review: Transforming View Volumes



Review: Basic Perspective Projection



similar triangles

$\frac{y'}{d} = \frac{y}{z} \rightarrow y' = \frac{y \cdot d}{z}$ **also** $x' = \frac{x \cdot d}{z}$ **but** $z' = d$

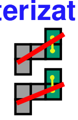
- nonuniform foreshortening
  - not affine

Post-Midterm Topics Covered

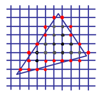
- rasterization
- interpolation/bary coords
- color
- lighting
- shading
- compositing
- clipping
- curves
- picking
- collision
- textures
- procedural approaches
- sampling
- virtual trackball
- visibility
- scientific visualization
- information visualization
- advanced rendering
- animation

Review: Rasterization

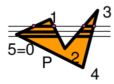
- lines: midpoint algorithm
  - optimized: Bresenham



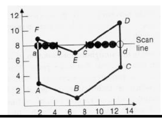
- polygons



  - flood fill



  - scanline algorithms
  - parity test for general case

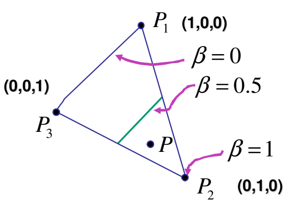


Review: Barycentric Coordinates

- weighted combination of vertices

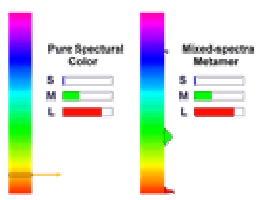
$$\begin{cases} P = \alpha \cdot P_1 + \beta \cdot P_2 + \gamma \cdot P_3 \\ \alpha + \beta + \gamma = 1 \\ 0 \leq \alpha, \beta, \gamma \leq 1 \end{cases}$$

"convex combination of points"



Review: Color

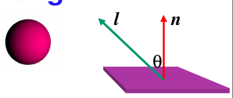
- color perception
  - color is combination of stimuli from 3 cones
  - metamer: identically perceived color caused by very different spectra



- simple model: based on RGB triples
- component-wise multiplication of colors
  - (a0,a1,a2) * (b0,b1,b2) = (a0*b0, a1*b1, a2*b2)

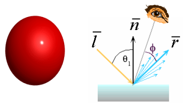
Review: Lighting

- reflection equations



$\mathbf{I}_{\text{diffuse}} = \mathbf{k_d}\, \mathbf{I}_{\text{light}}\, (\mathbf{n} \bullet \mathbf{l})$

$\mathbf{I}_{\text{specular}} = \mathbf{k_s} \mathbf{I}_{\text{light}} (\mathbf{v} \bullet \mathbf{r})^{n_{shiny}}$



R = 2 (**N** (**N** · **L**)) – **L**

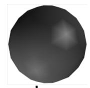
- full Phong lighting model
  - combine ambient, diffuse, specular components

$$\mathbf{I}_{\text{total}} = \mathbf{k_s} \mathbf{I}_{\text{ambient}} + \sum_{i=1}^{\#lights} \mathbf{I}_i (\mathbf{k_d}(\mathbf{n} \bullet \mathbf{l}_i) + \mathbf{k_s}(\mathbf{v} \bullet \mathbf{r}_i)^{n_{shiny}})$$

85

Review: Shading Models

- flat shading
  - compute Phong lighting once for entire polygon

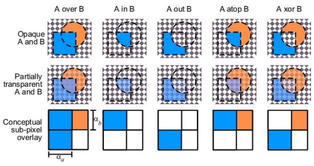


- Gouraud shading
  - compute Phong lighting at the vertices and interpolate lighting values across polygon
- Phong shading
  - compute averaged vertex normals
  - interpolate normals across polygon and perform Phong lighting across polygon

86

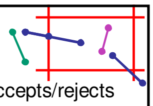
Review: Compositing

- specify opacity with alpha channel: (r,g,b,α)
  - α=1: opaque, α=.5: translucent, α=0: transparent
- **A** *over* **B**
  - **C** = α**A** + (1-α)**B**
- premultiplying by alpha
  - **C'** = γ **C, B'** = β**B, A'** = α**A**
  - **C'** = **B'** + **A'** - α**B'**
  - γ = β + α – αβ

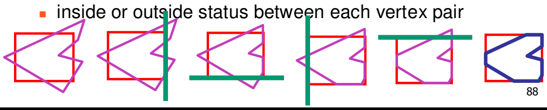


87

Review: Clipping

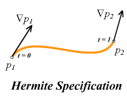


- Cohen Sutherland lines: combining trivial accepts/rejects
  - trivially accept lines: both endpoints inside all edges
    - outcode test: OC(p1)== 0 && OC(p2)==0
  - trivially reject lines: both endpoints outside same edge
    - outcode test: OC(p1) & OC(p2))!= 0 reject
  - otherwise, reduce to trivial: splitting into two segments
- Sutherman-Hodgeman polygons
  - for each viewport edge: clip polygon against edge
  - process input edge list to make output edge list
  - inside or outside status between each vertex pair

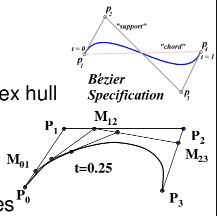


88

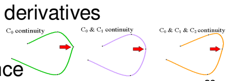
Review: Curves



- Hermite
  - endpoints and their derivatives
- Bezier
  - four control points
  - curve remains within their convex hull
  - subdivision construction



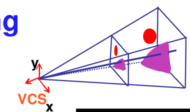
- continuity
  - C^0: share join point
  - C^1: share continuous derivatives
  - C^2: share continuous second derivatives
- B-splines
  - locality of control point influence



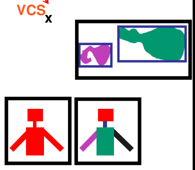
89

Review: Picking

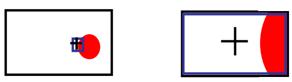
- manual ray intersection



- bounding extents
- backbuffer coding



- select/hit

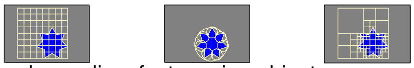


90

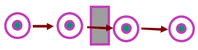
Review: Collision Detection

- naive approach very expensive: $O(n^2)$
- collision proxies

- spatial data structures to localize



- temporal sampling, fast moving objects

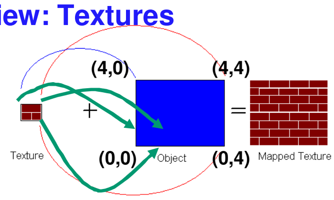


- responding to collisions

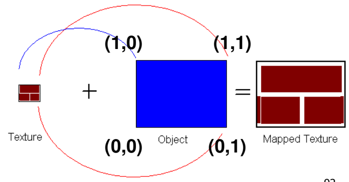
91

Review: Textures

glTexCoord2d(4, 4);
glVertex3d (x, y, z);



glTexCoord2d(1, 1);
glVertex3d (x, y, z);



92

Review: Procedural Approaches

- Perlin noise
  - coherency: smooth not abrupt changes
  - turbulence: multiple feature sizes

- particle systems

- fractal landscapes

- L-systems

93

Review: Sampling

- Shannon Sampling Theorem
  - continuous signal can be completely recovered from its samples iff sampling rate greater than twice maximum frequency present in signal
- sample past Nyquist Rate to avoid aliasing
  - twice the highest frequency component in the image's spectrum

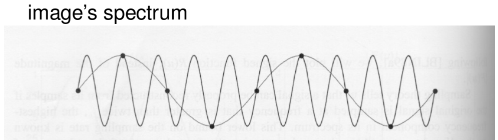
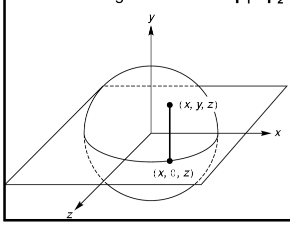


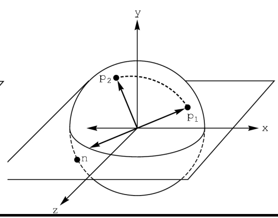
Fig. 14.17 Sampling below the Nyquist rate. (Courtesy of George Wolberg, Columbia University.)

94

Review: Virtual Trackball Rotation

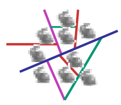
- correspondence:
  - moving point on plane from (x, 0, z) to (a, 0, c)
  - moving point on ball from $\mathbf{p}_1$ =(x, y, z) to $\mathbf{p}_2$ =(a, b, c)
- correspondence:
  - translating mouse from $\mathbf{p}_1$ (mouse down) to p_2 (mouse up)
  - rotating about axis $\mathbf{n} = \mathbf{p}_1 \times \mathbf{p}_2$ by arccos($\mathbf{p}_1 \cdot \mathbf{p}_2$ / $|\mathbf{p}_1|$ $|\mathbf{p}_2|$)



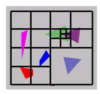


Review: Visibility

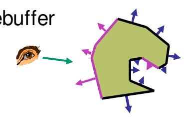
- painter's algorithm
  - back to front, incorrect
- BSP trees
  - build, then traverse



- Warnock's algorithm
  - subdivide viewport



- Z-buffer
  - depth buffer in addition to framebuffer
- backface culling
  - optimization for closed objects



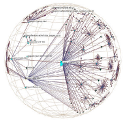
96

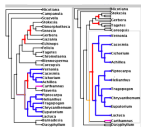
Review: Scientific Visualization

- volume graphics
- isosurfaces
  - extracting with Marching Cubes
- direct volume rendering
  - transfer functions to classify

Review: Information Visualization

- interactive visual representation of abstract data
  - help human perform some task more effectively
- techniques
  - overview, zoom and filter, details on demand
  - focus+context
  - linked views
  - small multiples
- visual channels
  - preattentive visual popout
  - categorical, ordered, quantitative data types

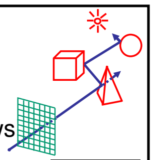




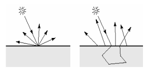
Review: Animation

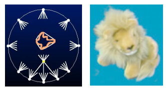
- traditional direct specification of motion curves
  - key framing: straight-ahead, layering
  - retiming
  - inverse kinematics
- procedural modeling
  - particle systems
- data-driven modeling
  - motion capture
- physics-based modeling
  - cloth, fluid simulation

Review: Advanced Rendering



- ray tracing
  - reflection, refraction, hard shadows
- subsurface scattering
  - marble, milk
- radiosity
  - diffuse lighting, soft shadows
- image-based rendering
  - store/access only pixels





Other Graphics Courses

- 424: Geometric Modelling
  - not offered next year
- 426: Computer Animation
  - will be offered next year
- 514: Image-Based Rendering - Heidrich
- 526: Algorithmic Animation- van de Panne
- 533A: Digital Geometry - Sheffer
- 533B: Animation Physics - Bridson
- 533C: Information Visualization - Munzner