15-462 Computer Graphics I

Lecture 6

Hierarchical Models

Projections and Shadows
Hierarchical Models
Basic Animation
[Angel Ch 5.10, 9.1-9.6]

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Roadmap

- Last lecture: Viewing and projection
- Today:
  - Shadows via projections
  - Hierarchical models
  - Basic animation
- Next: lighting and material properties
- Goal: background for Assignment 3 (next week)

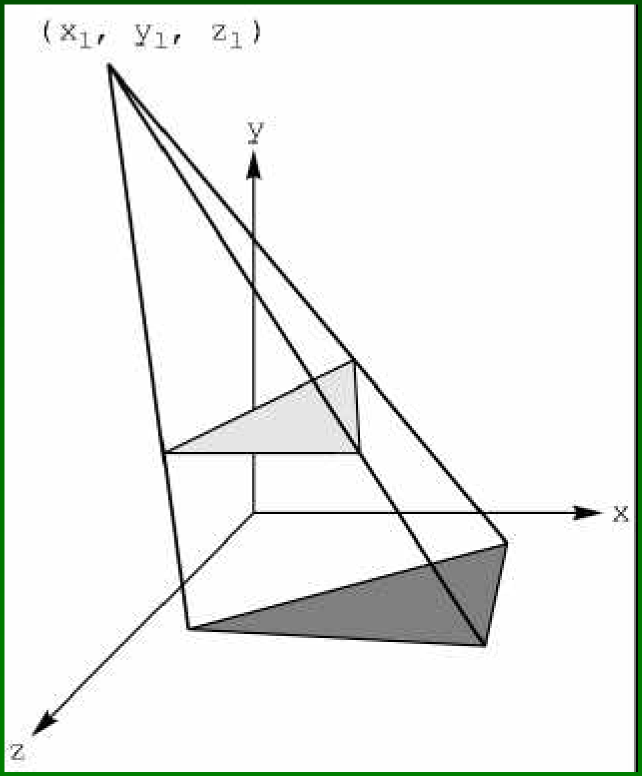
Shadow Algorithms

- With visibility tests
  - Accurate yet expensive
  - Example: ray casting or ray tracing
  - Example: 2-pass z-buffer

    [Foley, Ch. 16.4.4] [RTR 6.12]
- Without visibility tests (“fake” shadows)
  - Approximate and inexpensive
  - Using projection in model-view matrix
  - Examples: flight simulator, Assignment 3

Shadows via Projection

- Assume light source at $[x_l \;\; y_l \;\; z_l \;\; 1]^T$
- Assume shadow on plane y = 0
- Viewing ~ shadow projection
  - Center of projection ~ light
  - Viewing plane ~ shadow plane
- View plane in front of object
- Shadow plane behind object



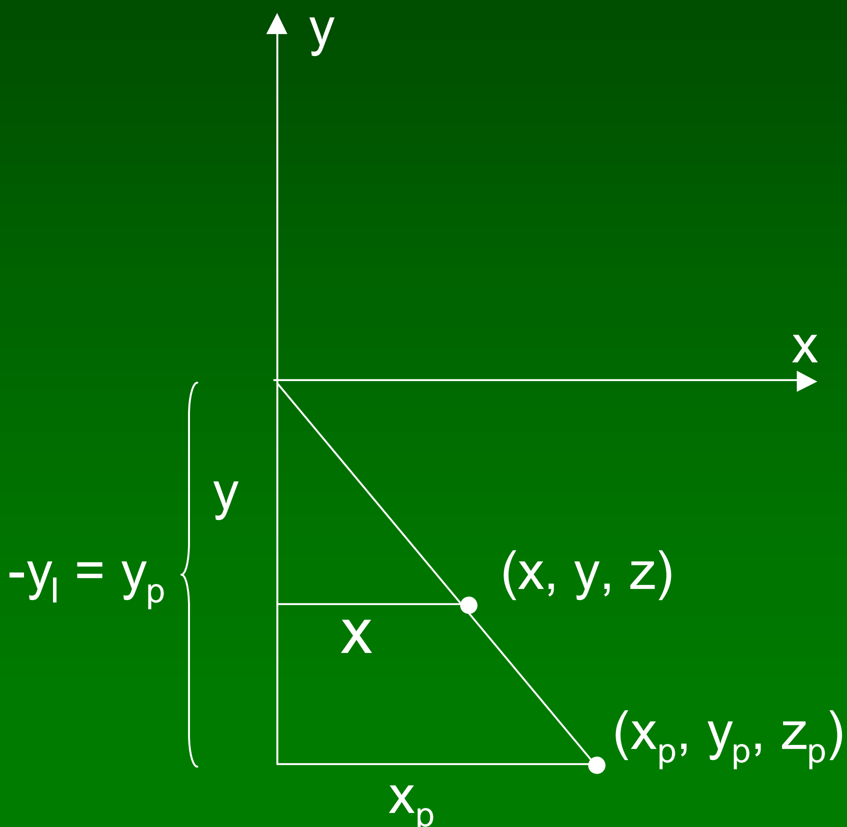
Shadow Projection Strategy

- Move light source to origin
- Apply appropriate projection matrix
- Move light source back
- Instance of general strategy: compose complex transformation from simpler ones!

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & -x_l \\ 0 & 1 & 0 & -y_l \\ 0 & 0 & 1 & -z_l \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Derive Equation

- Now, light source at origin



$$\frac{x_p}{y_p} = \frac{x}{y} \qquad \text{(see picture)}$$

$$y_p = -y_l \qquad \text{(moved light)}$$

$$x_p = \frac{x}{y} y_p = -\frac{x}{y/y_l}$$

$$z_p = \frac{z}{y} y_p = -\frac{x}{y/y_l}$$

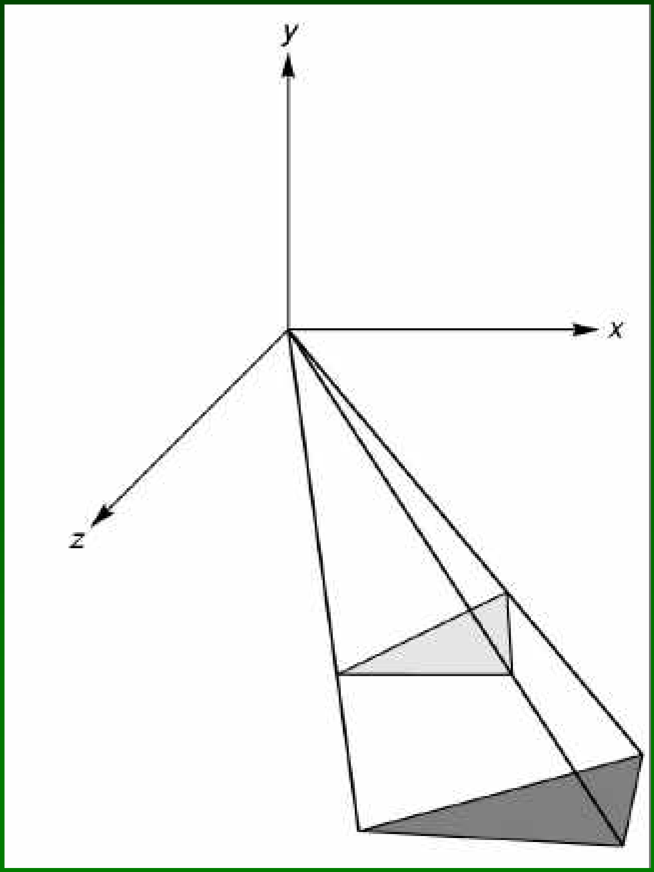
Light Source at Origin

- After translation, solve

$$\mathrm{M}\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = w\begin{bmatrix} -\frac{x}{y/y_l} \\ -y_l \\ -\frac{z}{y/y_l} \\ 1 \end{bmatrix}$$

- w can be chosen freely
- Use w = $-y/y_l$

$$\mathrm{M}\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ -y/y_l \end{bmatrix}$$



Shadow Projection Matrix

- Solution of previous equation

$$\mathrm{M} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -\frac{1}{y_l} & 0 & 0 \end{bmatrix}$$

- Total shadow projection matrix

$$\mathrm{S} = \mathrm{T}^{-1}\mathrm{M}\mathrm{T} = \ldots$$

Implementation

- Recall column-major form

```
GLfloat m[16] =
{1.0, 0.0, 0.0, 0.0,
  0.0, 1.0, 0.0, -1.0/yl,
  0.0, 0.0, 1.0, 0.0,
  0.0, 0.0, 0.0, 0.0};
```

- Assume drawPolygon(); draws object

Saving State

- Assume xl, yl, zl hold light coordinates

```
glMatrixMode(GL_MODELVIEW);
drawPolygon();    /* draw normally */

glPushMatrix();    /* save current matrix */
glTranslatef(xl, yl, zl);       /* translate back */
glMultMatrixf(m);               /* project */
glTranslatef(-xl, -yl, -zl);  /* move light to origin */
drawPolygon();    /* draw polygon again for shadow */
glPopMatrix();      /* restore original transformation */
...
```

The Matrix and Attribute Stacks

- Mechanism to save and restore state
  - glPushMatrix();
  - glPopMatrix();
- Apply to current matrix
- Can also save current attribute values
  - Examples: color, lighting
  - glPushAttrib(GLbitfield *mask*);
  - glPopAttrib();
  - Mask determines which attributes are saved

Drawing on a Surface

- Shimmering when drawing shadow on surface
- Due to limited precision depth buffer
- Either displace surface or shadow slightly (glPolygonOffset in OpenGL)
- Or use special properties of scene
- Or use general technique
  1. Set depth buffer to read-only, draw surface
  2. Set depth buffer to read-write, draw shadow
  3. Set color buffer to read-only, draw surface again
  4. Set color buffer to read-write

Outline

- Projections and Shadows
- Hierarchical Models
- Basic Animation

Hierarchical Models

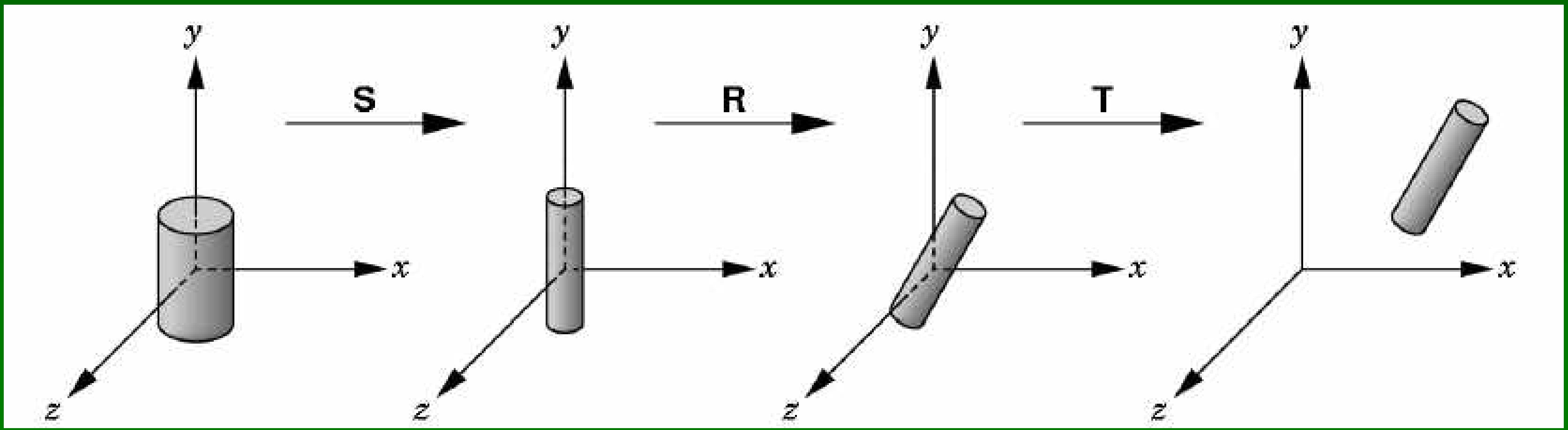
- Many graphical objects are structured
- Exploit structure for
  - Efficient rendering
  - Example: bounding boxes (later in course)
  - Concise specification of model parameters
  - Example: joint angles
  - Physical realism
- Structure often naturally hierarchical

Instance Transformation

- Often we need several instances of an object
  - Wheels of a car
  - Arms or legs of a figure
  - Chess pieces
- Instances can be shared across space or time
- Encapsulate basic object in a function
- Object instances are created in “standard” form
- Apply transformations to different instances
- Typical order: scaling, rotation, translation

Sample Instance Transformation

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glTranslatef(...);
glRotatef(...);
glScalef(...);
gluCylinder(...);
```



Display Lists

- Sharing display commands
- Display lists are stored on the server
- May contain drawing commands and transfns.
- Initialization:

```
GLuint torus = glGenLists(1);
glNewList(torus, GL_COMPILE);
  Torus(8, 25);
glEndList();
```

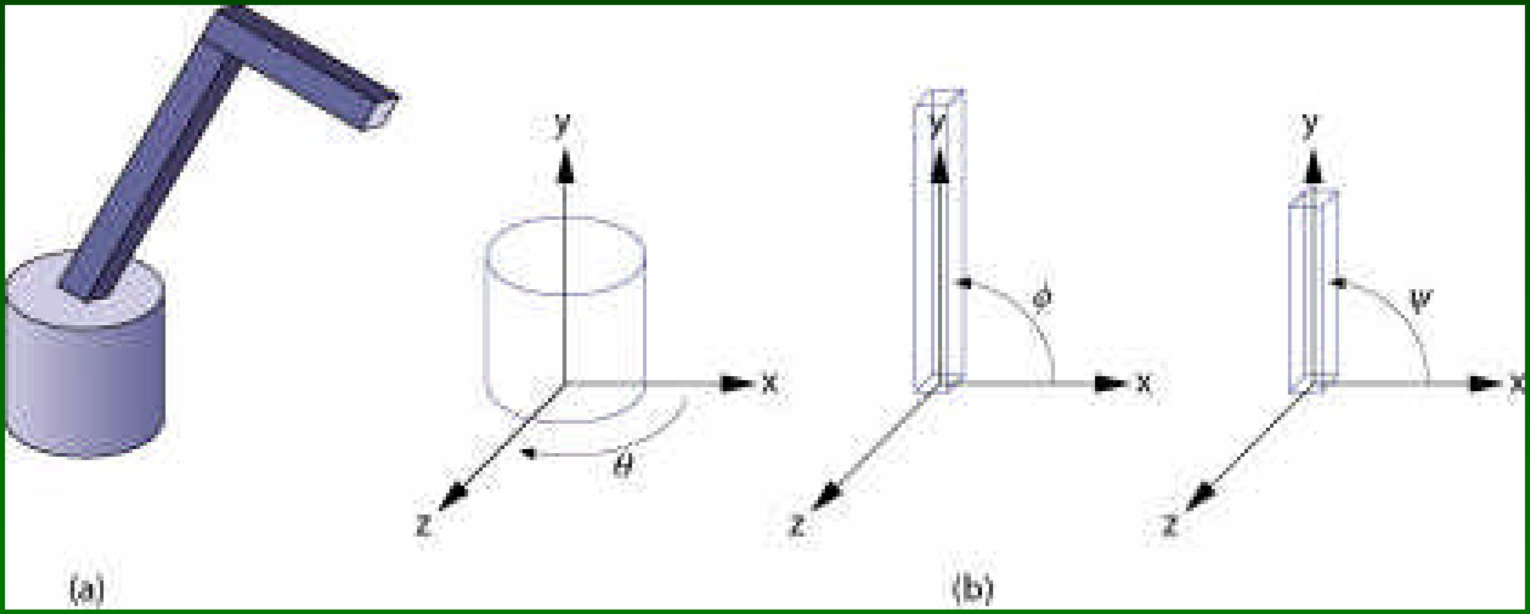
- Use: glCallList(torus);
- In animation, can also share at different times

Display Lists Caveats

- Store only values of expressions
- Display lists cannot be changed or updated
- Only store commands that change server state
- Effect of executing display list depends on current transformations and attributes
- Display lists may be hierarchical
  – One list may call another
  – Can be useful for hierarchical objects
  – Some implementation-dependent nesting limit

Drawing a Compound Object

- Example: simple "robot arm"



Base rotation θ, arm angle ϕ, joint angle ψ

Interleave Drawing & Transformation

- h1 = height of base, h2 = length of lower arm

```
void drawRobot(GLfloat theta, GLfloat phi, GLfloat psi)
{
    glRotatef(theta, 0.0, 1.0, 0.0);
    drawBase();
    glTranslatef(0.0, h1, 0.0);
    glRotatef(phi, 0.0, 0.0, 1.0);
    drawLowerArm();
    glTranslatef(0.0, h2, 0.0);
    glRotatef(psi, 0.0, 0.0, 1.0);
    drawUpperArm();
}
```

Assessment of Interleaving

- Compact
- Correct “by construction”
- Efficient
- Inefficient alternative:

```
glPushMatrix();          glPushMatrix();          ...etc...
glRotatef(theta, ...);   glRotatef(theta, ...);
drawBase();              glTranslatef(...);
glPopMatrix();           glRotatef(phi, ...);
                         drawLowerArm();
                         glPopMatrix();
```

- Count number of transformations

Hierarchical Objects and Animation

- Drawing functions are time-invariant

  drawBase(); drawLowerArm(); drawUpperArm();

- Can be easily stored in display list
- Change parameters of model with time
- Redraw when idle callback is invoked

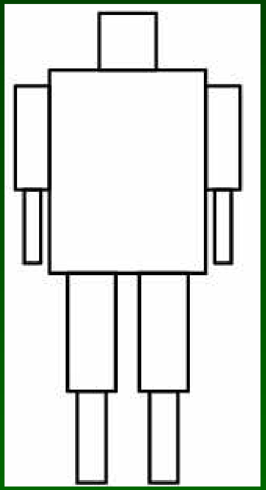
A Bug to Watch

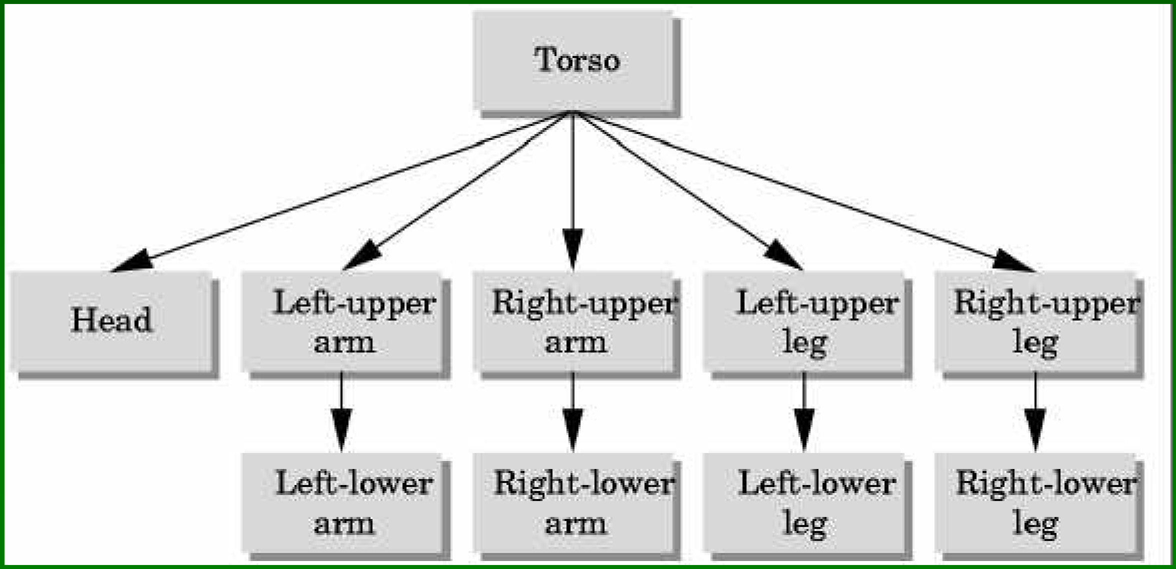
```
GLfloat theta = 0.0; ...;  /* update in idle callback */
GLfloat phi = 0.0; ...;  /* update in idle callback */
GLuint arm = glGenLists(1);
/* in init function */
glNewList(arm, GL_COMPILE);
   glRotatef(theta, 0.0, 1.0, 0.0);
   drawBase();
   ...
   drawUpperArm();
glEndList();
/* in display callback */
glCallList(arm);
```

What is wrong?

More Complex Objects

- Tree rather than linear structure
- Interleave along each branch
- Use push and pop to save state





Hierarchical Tree Traversal

- Order not necessarily fixed
- Example:

```
void drawFigure()
{
  glPushMatrix();  /* save */
  drawTorso();

  glTranslatef(...); /* move head */
  glRotatef(...);     /* rotate head */
  drawHead();
  glPopMatrix();   /* restore */

  glPushMatrix();
  glTranslatef(...);
  glRotatef(...);
  drawUpperArm();
  glTranslatef(...)
  glRotatef(...)
  drawLowerArm();
  glPopMatrix();
  ... }
```

Using Tree Data Structures

- Can make tree form explicit in data structure

```
typedef struct treenode
{
  GLfloat m[16];
  void (*f) ( );
  struct treenode *sibling;
  struct treenode *child;
} treenode;
```

Initializing Tree Data Structure

- Initializing transformation matrix for node

```
treenode torso, head, ...;
/* in init function */
glLoadIdentity();
glRotatef(...);
glGetFloatv(GL_MODELVIEW_MATRIX, torso.m);
```

- Initializing pointers

```
torso.f = drawTorso;
torso.sibling = NULL;
torso.child = &head;
```

Generic Traversal

- Recursive definition

```
void traverse (treenode *root)
{
  if (root == NULL) return;
  glPushMatrix();
  glMultMatrixf(root->m);
  root->f();
  if (root->child != NULL) traverse(root->child);
  glPopMatrix();
  if (root->sibling != NULL) traverse(root->sibling);
}
```

- C is really not the right language for this

Outline

- Projections and Shadows
- Hierarchical Models
- Basic Animation

Unified View of Computer Animation

- Models with parameters
  - Polygon positions, control points, joint angles, ...
  - *n* parameters define n-dimensional state space
- Animation defined by path through state space
  - Define initial state, repeat:
  - Render the image
  - Move to next point (following motion curves)
- Animation = specifying state space trajectory

Animation vs Modeling

- Modeling: what are the parameters?
- Animation: how do we vary the parameters?
- Sometimes boundary not clear
- Build models that are easy to control
- Hierarchical models often easy to control

Basic Animation Techniques

- Traditional (frame by frame)
- Keyframing
- Procedural techniques
- Behavioral techniques
- Performance-based (motion capture)
- Physically-based (dynamics)

Traditional Cel Animation

- Film runs at 24 frames per second (fps)
- Video at 30 frames per second
- Production process critical: render farms
- Artistic issues: story and style

Traditional Animation Process

- Story board: sequence of sketches with story
- Key frames
  - Important frames as line drawings
  - Motion-based description
  - Example: beginning of stride, end of stride
- Inbetweens: draw remaining frames
- Painting: redraw onto acetate cels, color them

Layered Motion

- Multiple layers of animation
  - Reuse background
  - Multiple parallel animators
  - Supported by transparent acetate for drawing
- Also used in computer animation
- Example: painters algorithm for hidden surface removal

Storyboard Examples [A Bug's Life]

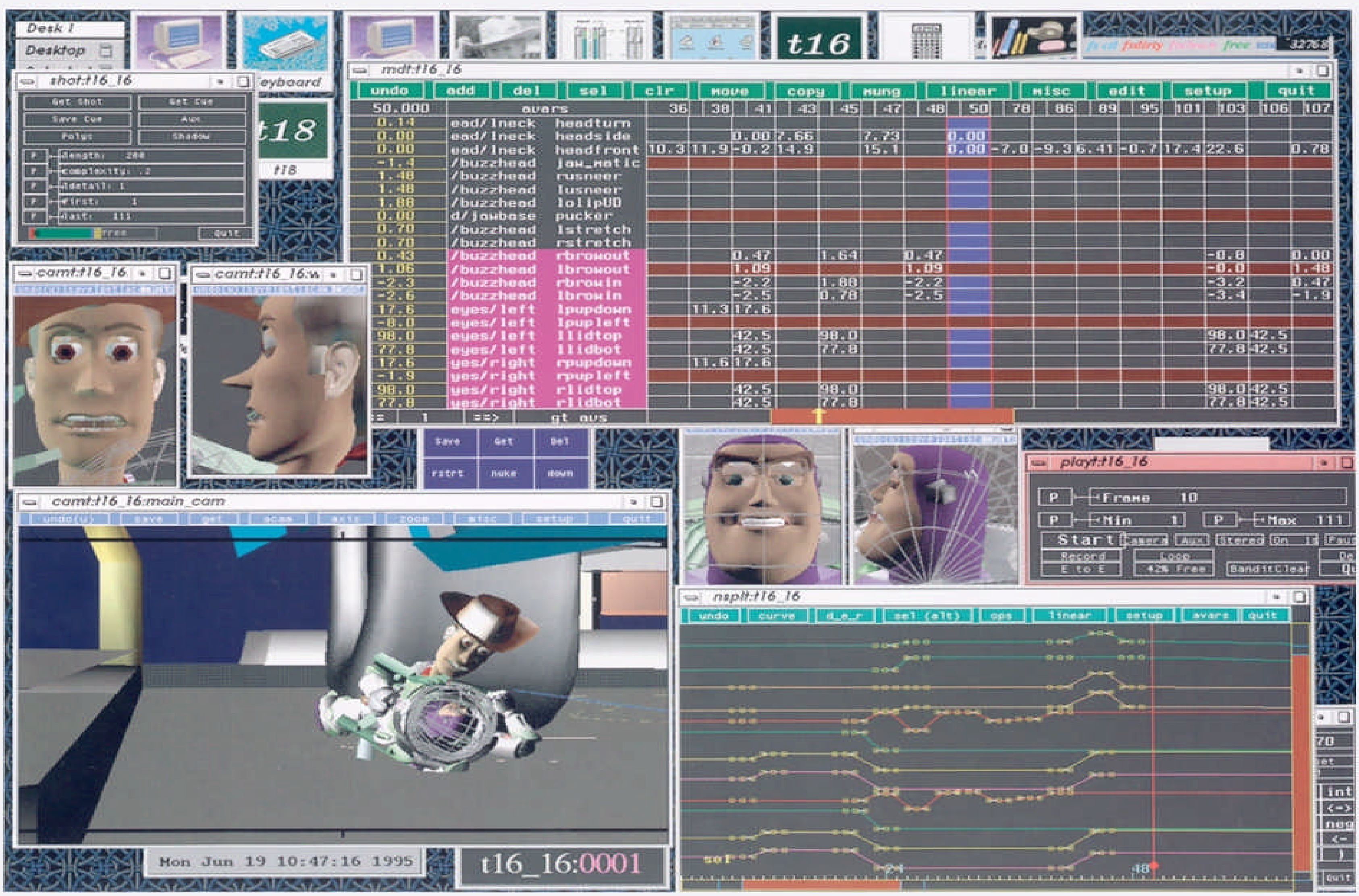
Computer Assisted Animations

- Eliminate human labor, bottom to top
- Computerized cel painting
  – Digitize line drawing, color using seed fill
  – Widely used in production (e.g., Lion King)
- Cartoon inbetweening
  – Interpolate between two drawings (morphing)
  – Difficult to make look natural
  – Choice of parameters?
  – Rarely used in production

True Computer Animations

- Generate images by rendering a 3D model
- Vary parameters to produce animation
- Brute force
  - Manually set the parameters for every frame
  - 1440n values per minute for n parameters
  - Maintenance problem
- Computer keyframing
  - Lead animators create important frames
  - Computers draw inbetweens from 3D(!)
  - Dominant production method

Example: From Toy Story



Some Research Issues

- Inverse kinematics
  - How to plot a path through state space
  - Multiple degrees of freedom
  - Also important in robotics
- Physical accuracy
  - Collision detection
  - Computer graphics: only needs to look right
  - Simulation: must follow model correctly

Summary

- Projections and Shadows
- Hierarchical Models
- Basic Animation

Preview

- Tuesday – lighting and shading
- Assignment 2 out today
- Due in one week (Thursday, before lecture)