Computer Graphics (CS 543)
Lecture 7 (Part 3): Hierarchical 3D Models

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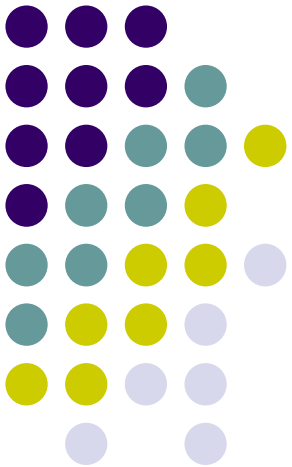
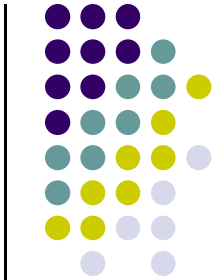
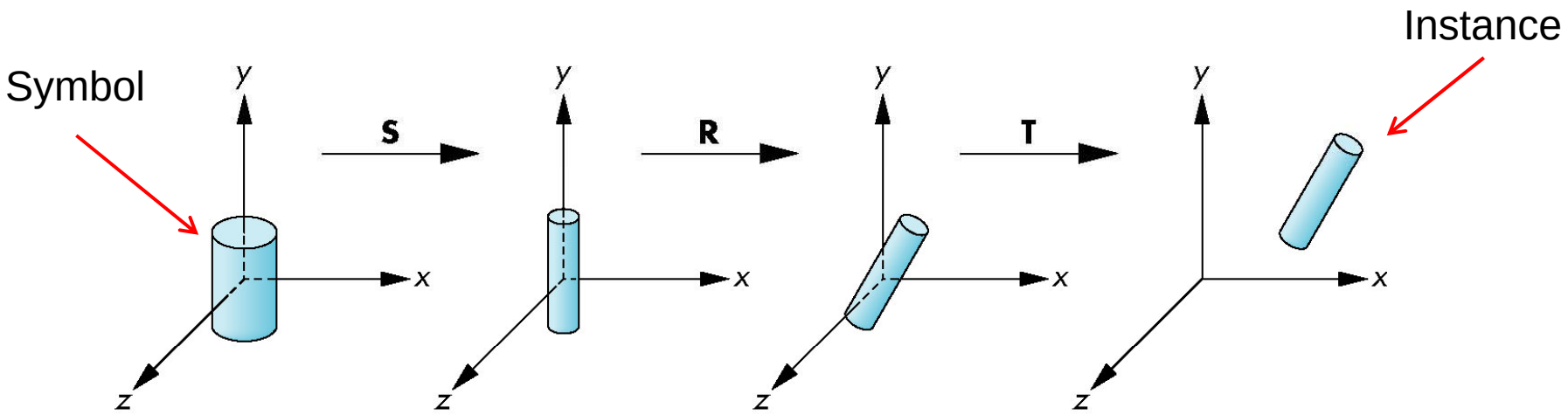


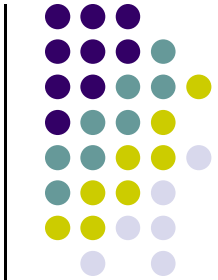
Instance Transformation



- Start with unique object (a *symbol*)
- Each appearance of object in model is an ***instance***
  - Must scale, orient, position
  - Defines instance transformation



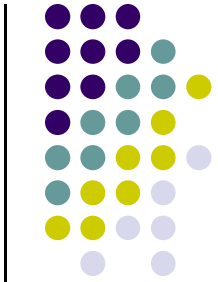
Symbol-Instance Table



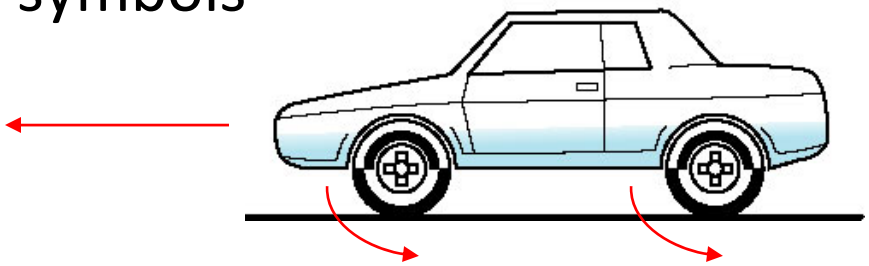
Can store a model by assigning number to each symbol and storing parameters for instance transformation

Symbol	Scale	Rotate	Translate
1 2 3 1 1 . .	s_x, s_y, s_z	$\theta_x, \theta_y, \theta_z$	d_x, d_y, d_z

Relationships in Car Model

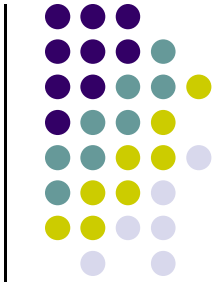


- Symbol-instance table does not show relationships between parts of model
- Consider model of car
  - Chassis (body) + 4 identical wheels
  - Two symbols



- Relationship: Rate of forward motion determined by rotational speed of wheels

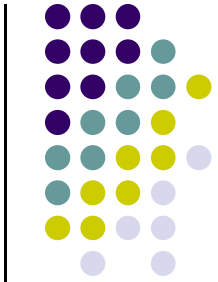
Structure using Function Calls



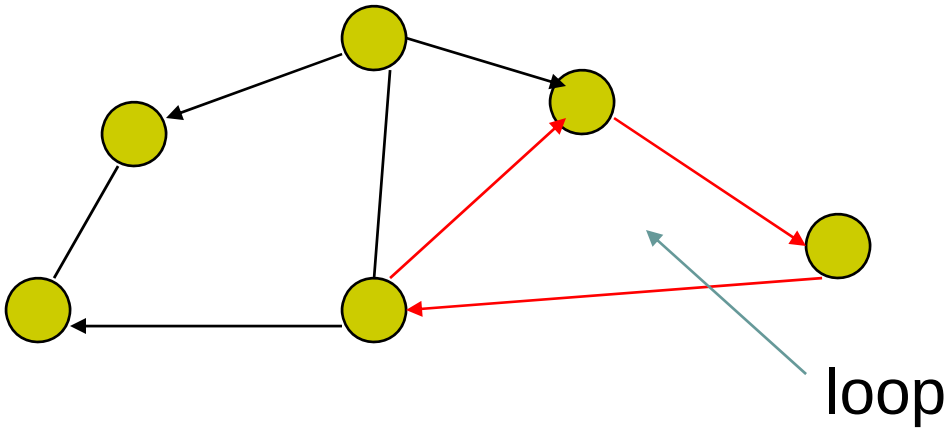
```
car(speed)
{
    chassis()
    wheel(right_front);
    wheel(left_front);
    wheel(right rear);
    wheel(left_rear);
}
```

- Fails to show relationships well
- Look at problem using a graph

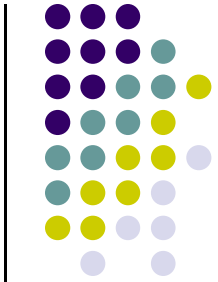
Graphs



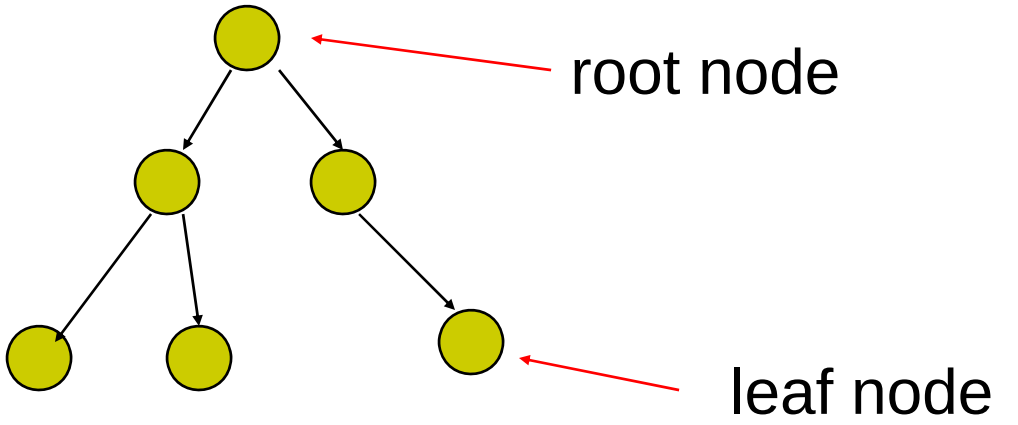
- Set of *nodes* and *edges (links)*
- Edge connects a pair of nodes
  - Directed or undirected
- *Cycle*: directed path that is a loop



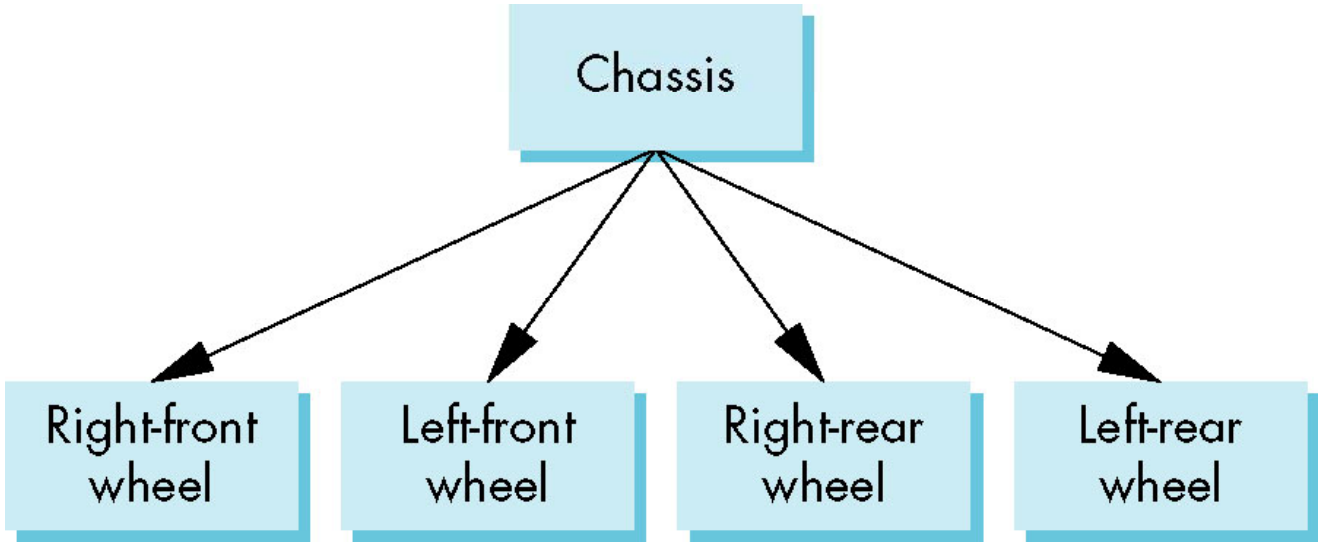
Tree



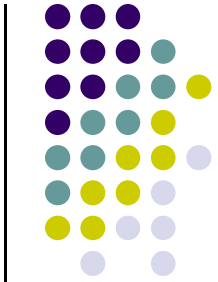
- Graph in which each node (except the root) has exactly one parent node
  - May have multiple children
  - Leaf or terminal node: no children



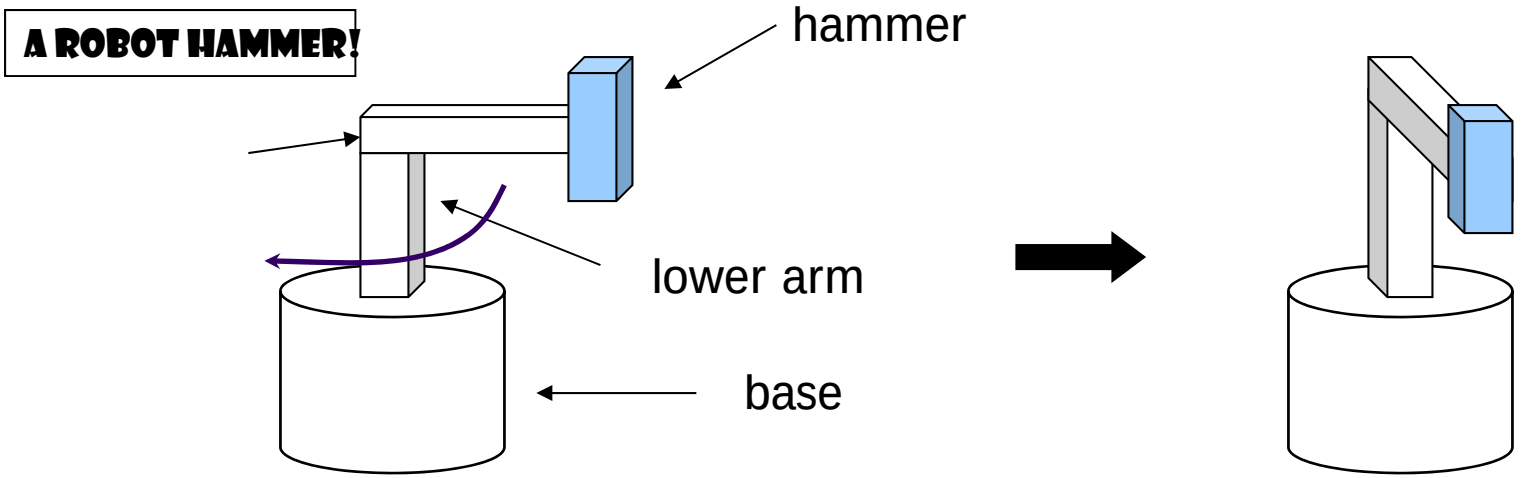
Tree Model of Car



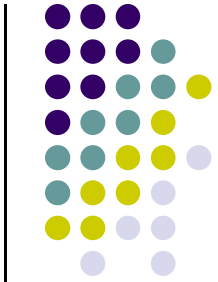
Hierarchical Transforms



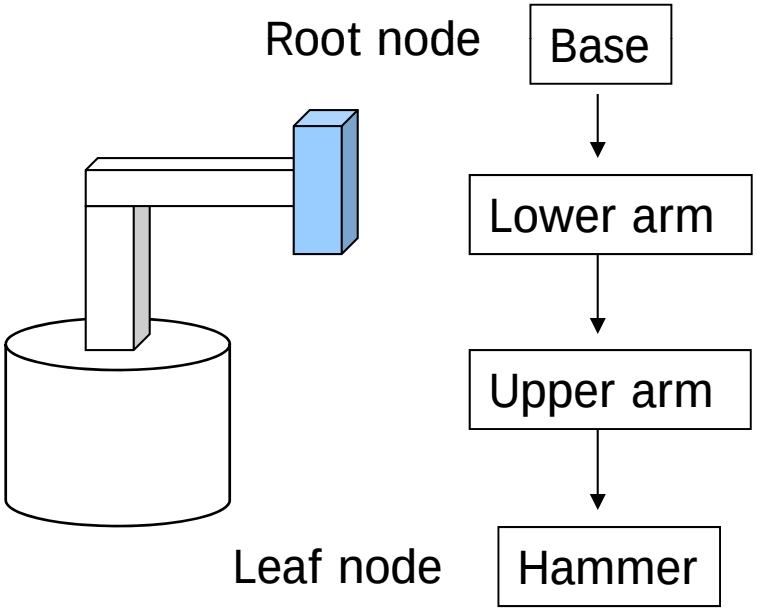
- Robot arm: Many small parts
- Attributes (position, orientation, etc) depend on each other



Hierarchical Transforms



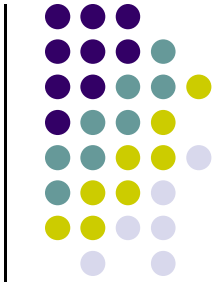
- Object dependency description using tree structure



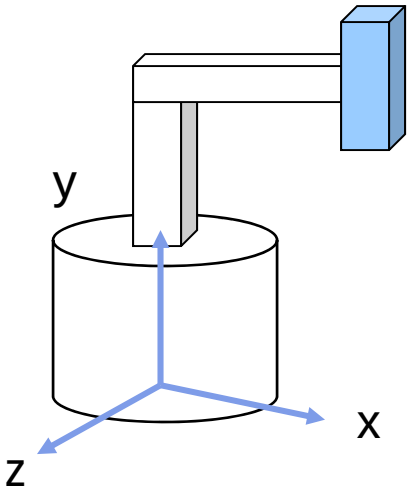
Object position and orientation can be affected by its parent, grand-parent, grand-grand-parent ... nodes

Hierarchical representation is known as Scene Graph

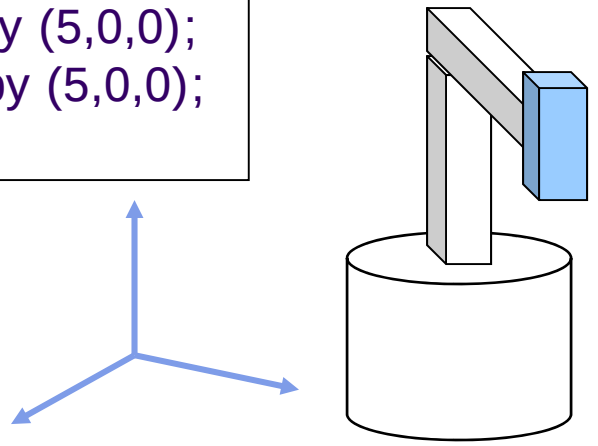
Transformations



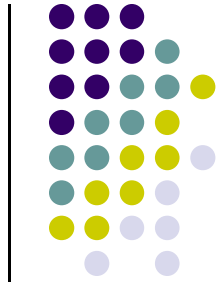
- Two ways to specify transformations:
  - **(1) Absolute transformation:** each part of the object is transformed independently relative to the origin




```
Translate the base by (5,0,0);
Translate the lower arm by (5,0,0);
Translate the upper arm by (5,0,0);
...
```

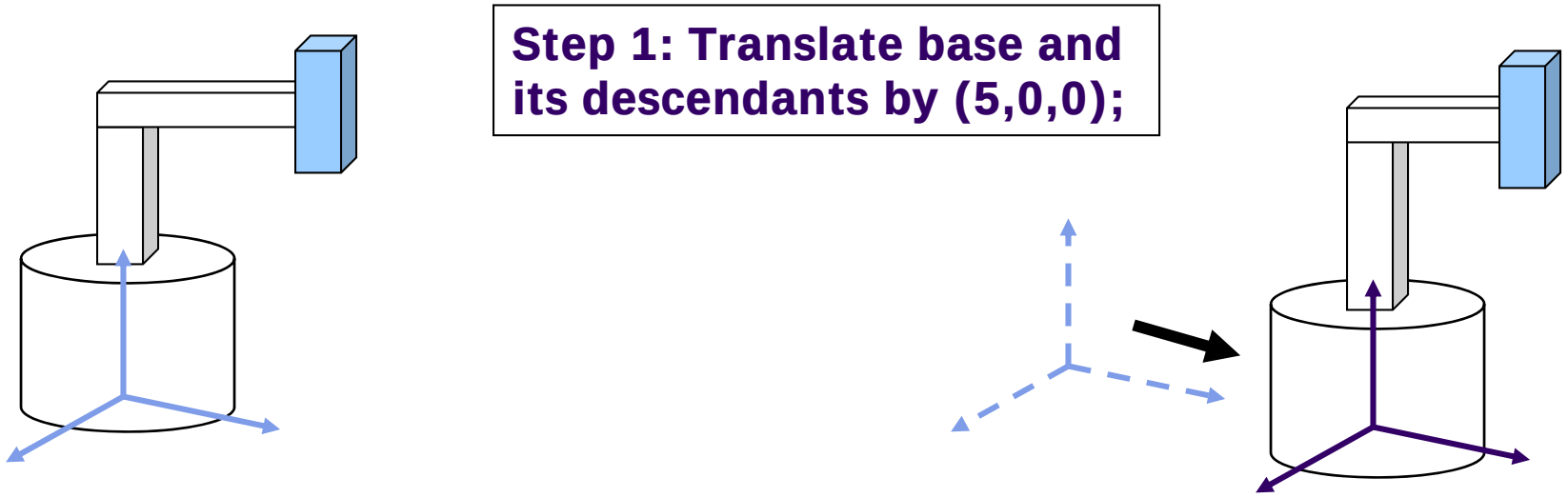


Relative Transformation

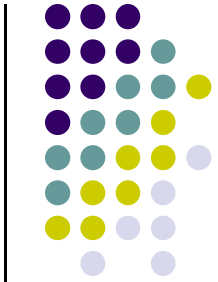


A better (and easier) way:

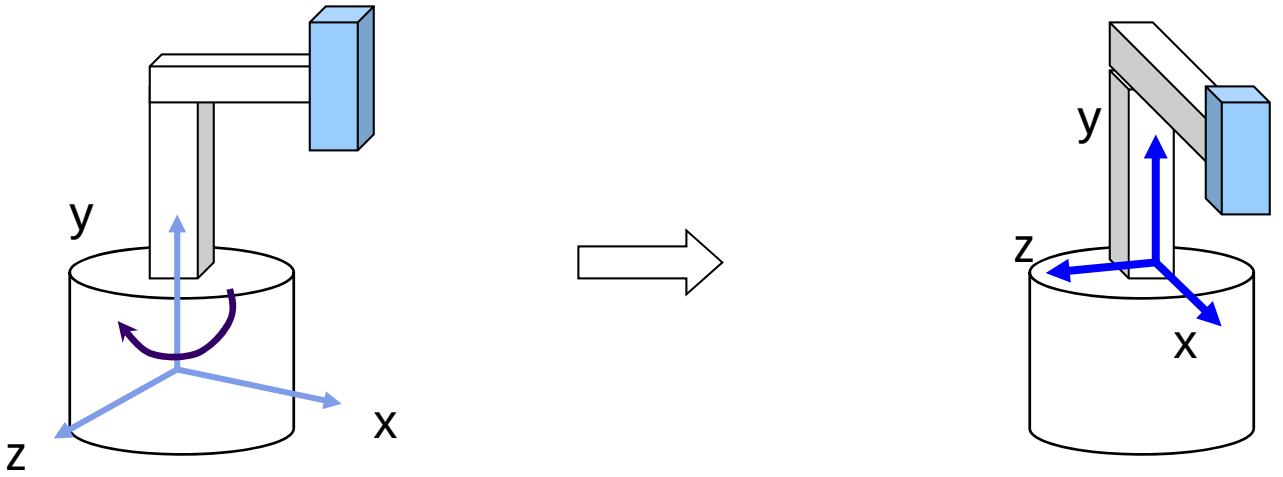
(2) **Relative transformation:** Specify the transformation for each object relative to its parent



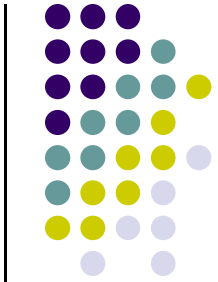
Relative Transformation



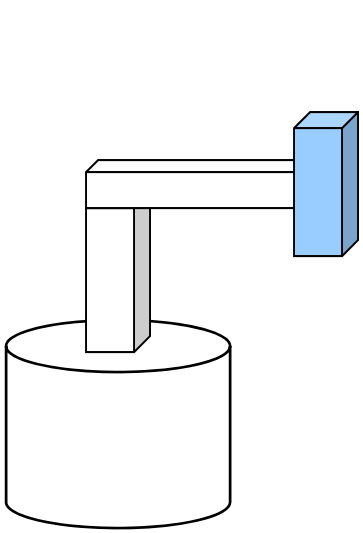
Step 2: Rotate the lower arm and all its descendants relative to the base's local y axis by -90 degree

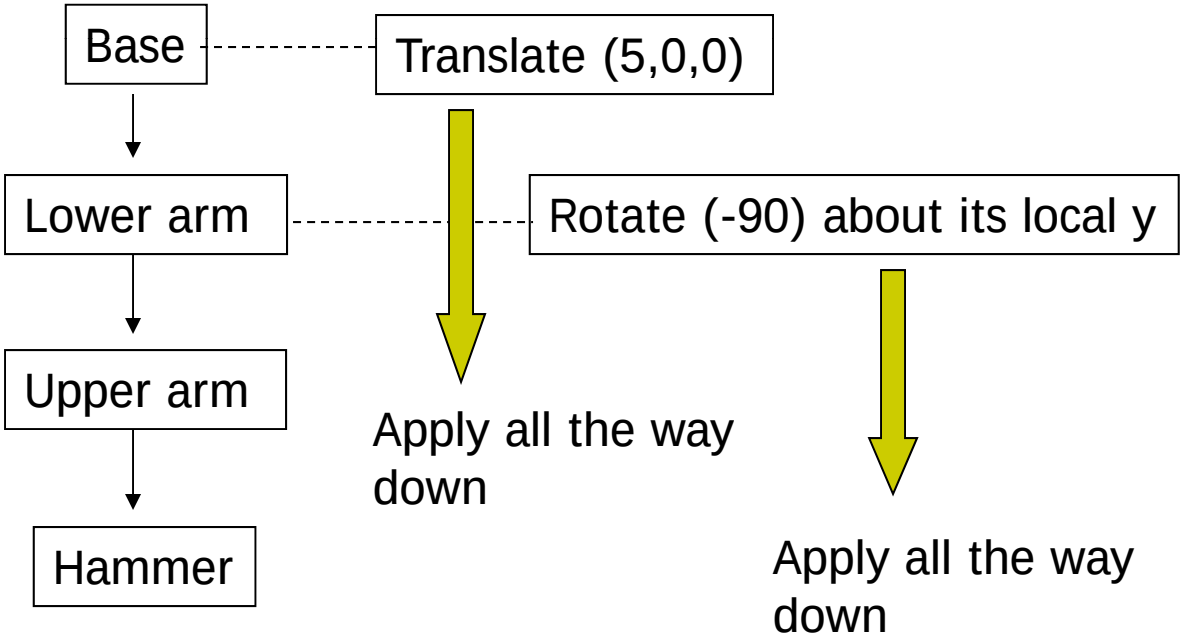


Relative Transformation

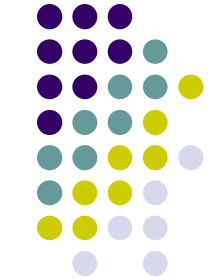


- Represent relative transformation using scene graph

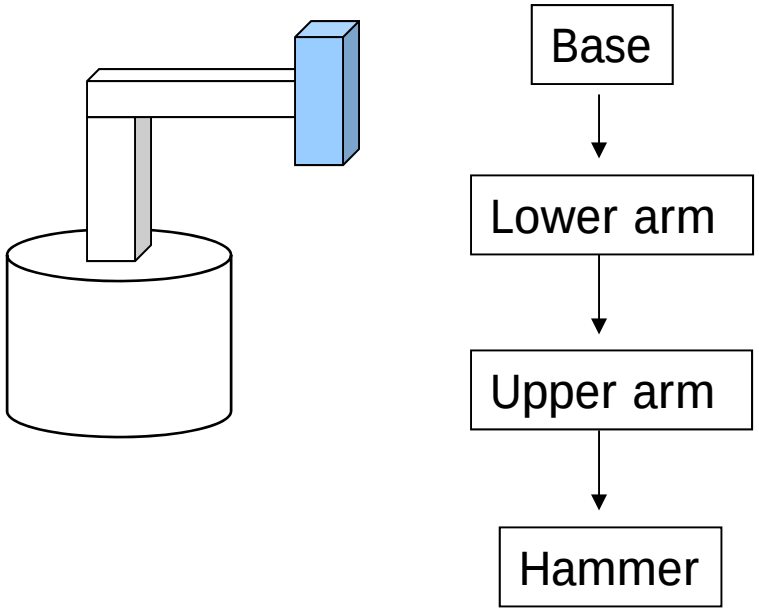




Hierarchical Transforms Using OpenGL

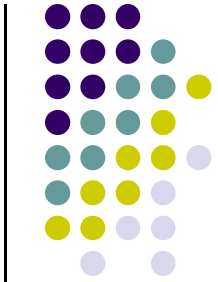


- Translate base and all its descendants by (5,0,0)
- Rotate lower arm and its descendants by -90 degree about local y




```
ctm = LoadIdentity();

... // setup your camera

ctm = ctm * Translatef(5,0,0);

Draw_base();

ctm = ctm * Rotatef(-90, 0, 1, 0);

Draw_lower _arm();
Draw_upper_arm();
Draw_hammer();
```

Hierarchical Modeling

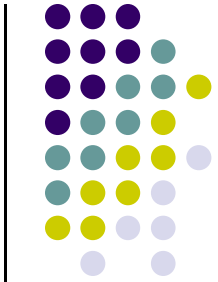


- Previous CTM had 1 level
- **Hierarchical modeling:** extend CTM to stack with multiple levels using linked list

Current top
Of CTM stack

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

PushMatrix



- **PushMatrix( ):** Save current modelview matrix in stack
- Positions 1 & 2 in linked list are same after PushMatrix
- Further Rotate, Scale, Translate affect only top matrix

Before PushMatrix

Current top
Of CTM stack →

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

After PushMatrix

Current top
Of CTM stack →

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

↓

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

PopMatrix

- **PopMatrix( ):** Delete position 1 matrix, position 2 matrix becomes top

Before PopMatrix

Current top
Of CTM stack

$$\begin{pmatrix} 1 & 5 & 4 & 0 \\ 0 & 2 & 2 & 0 \\ 0 & 6 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

After PopMatrix

Current top
Of CTM stack

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

PopMatrix and PushMatrix Illustration

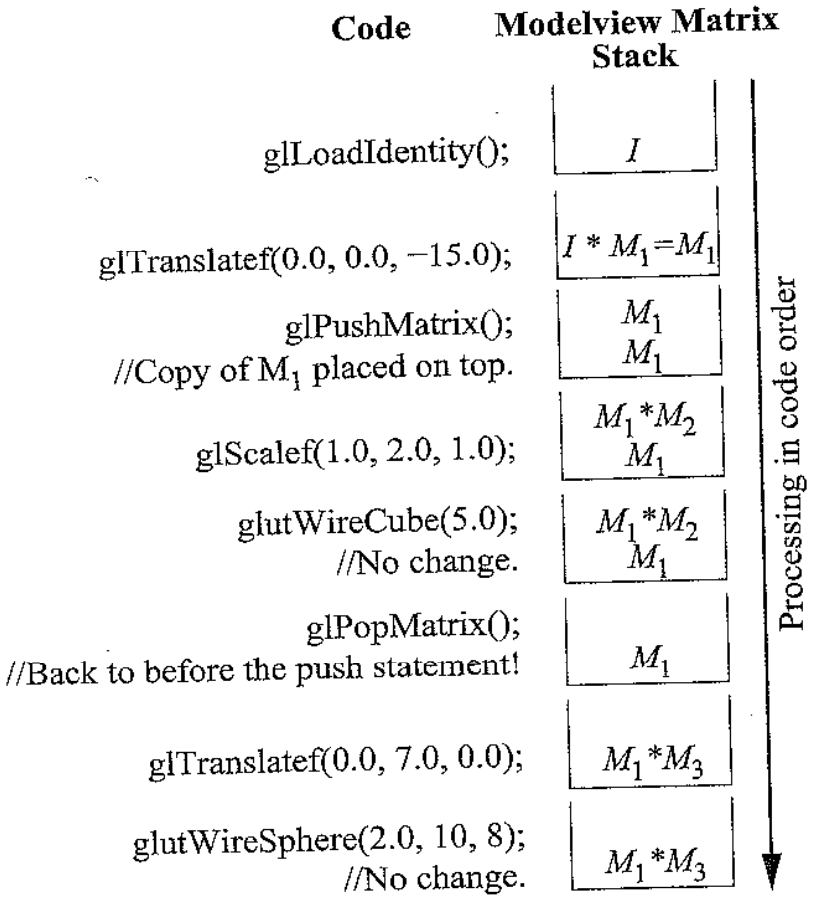
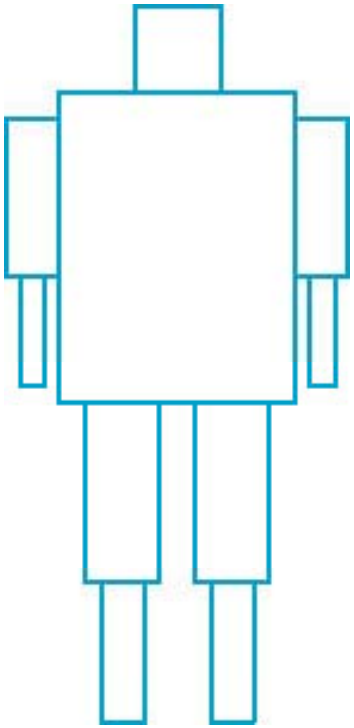


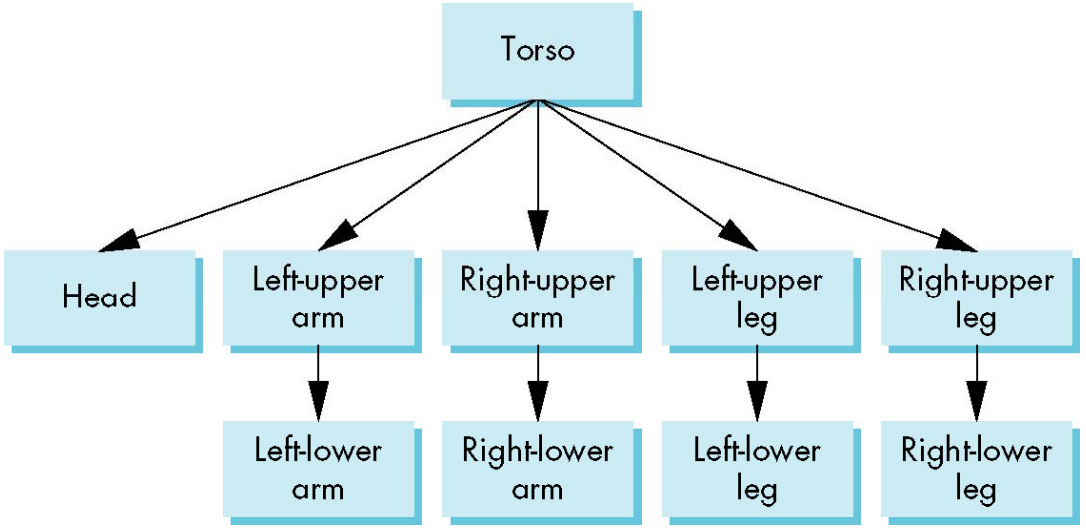
Figure 4.19: Transitions of the modelview matrix stack.

- Note: Diagram uses old glTranslate, glScale, etc commands
- We want same behavior though

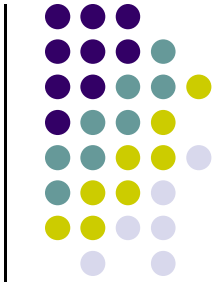
Ref: Computer Graphics Through OpenGL by Guha

Humanoid Figure



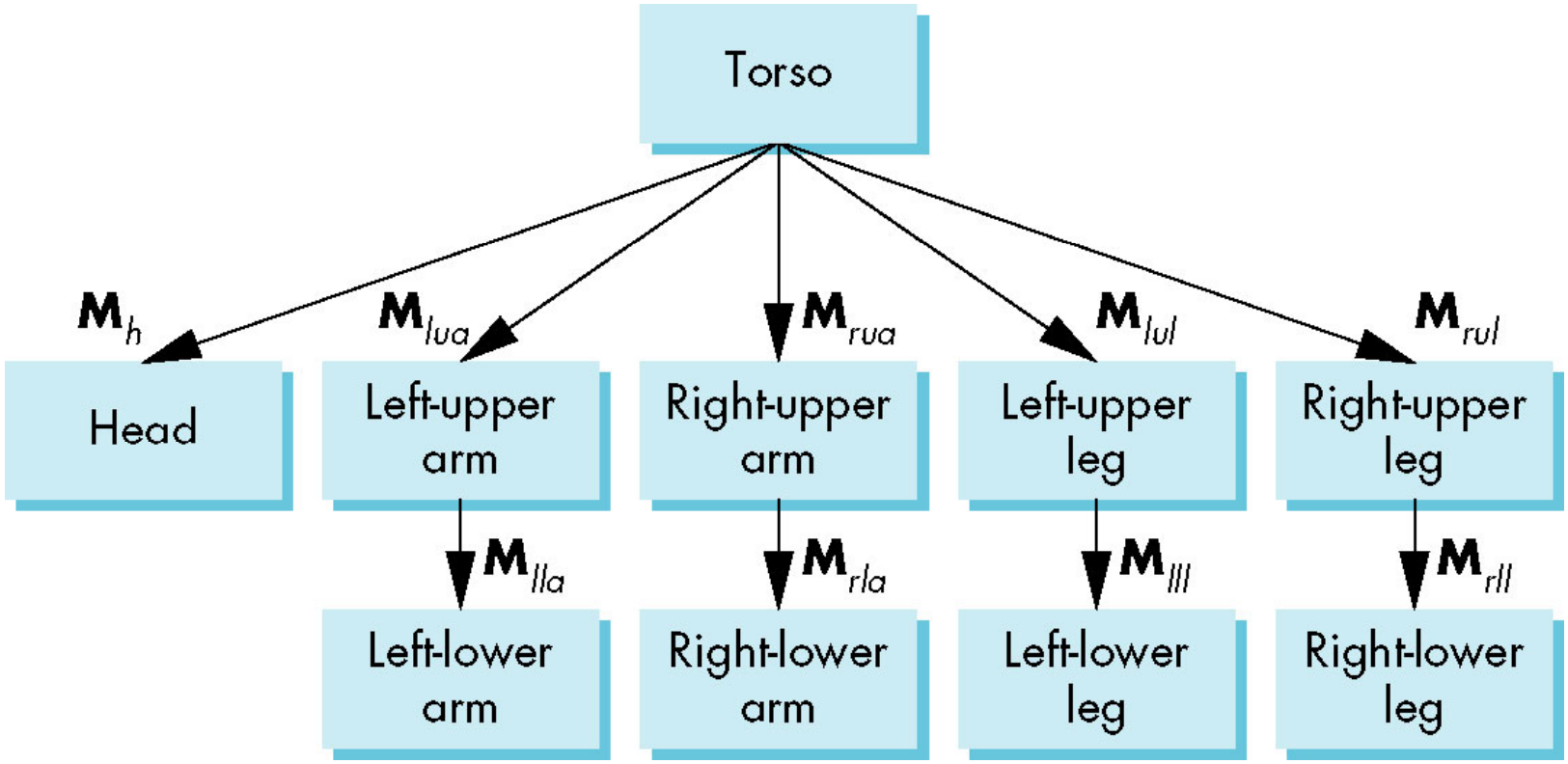


Building the Model

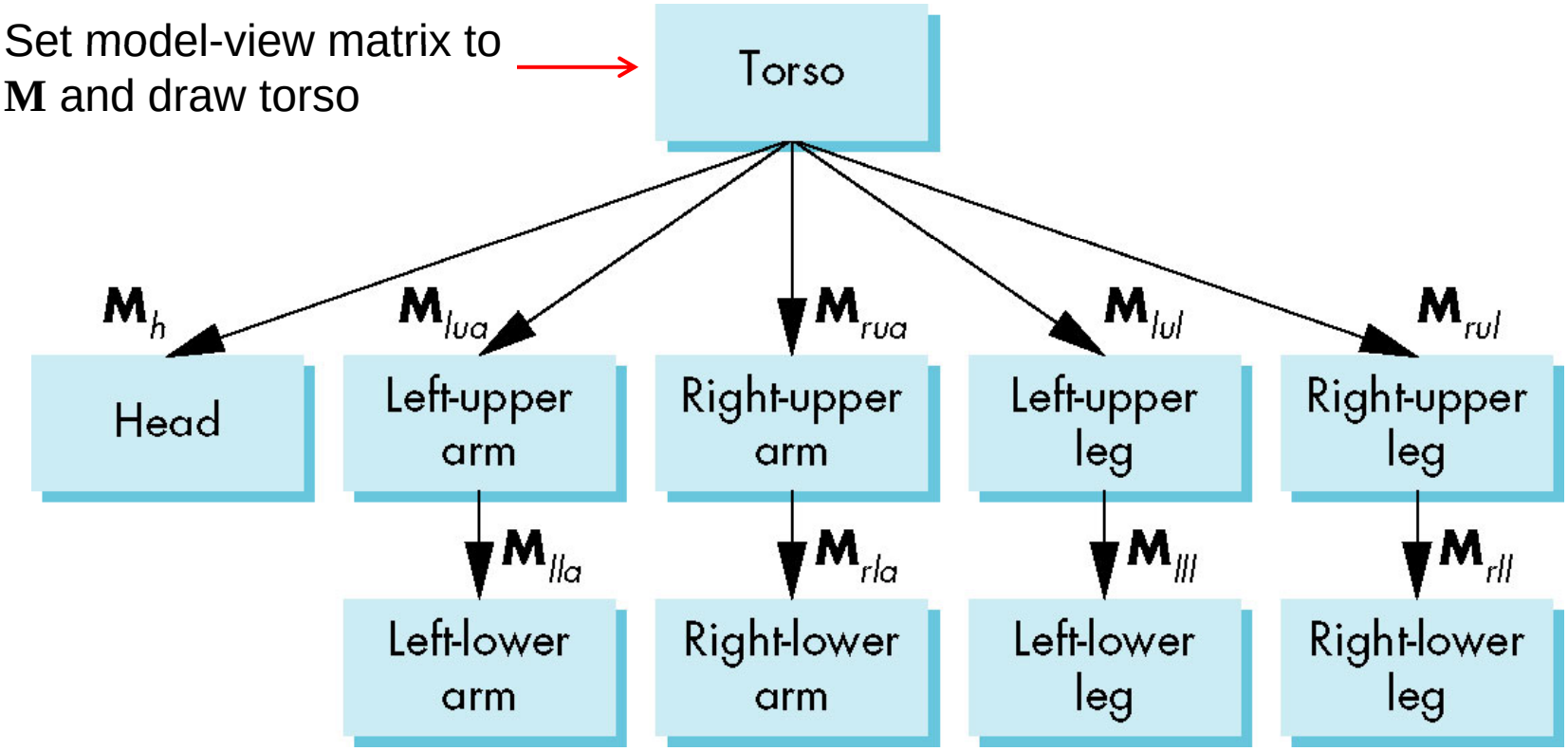


- Can build model using simple shapes
- Access parts through functions
  - **`torso()`**
  - **`left_upper_arm()`**
- Matrices describe position of node with respect to its parent
  - $\mathbf{M}_{\text{lla}}$ positions left lower leg with respect to left upper arm

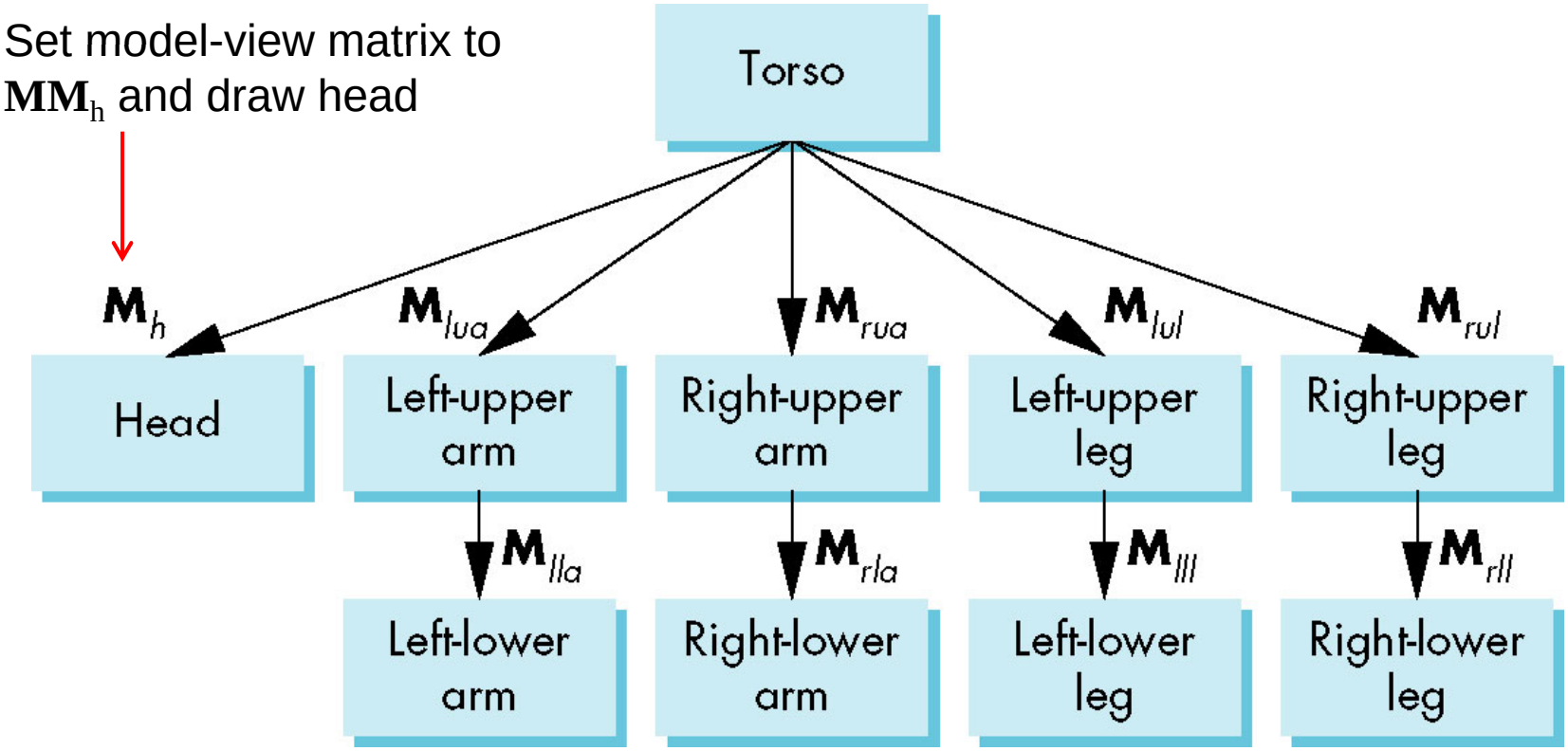
Tree with Matrices



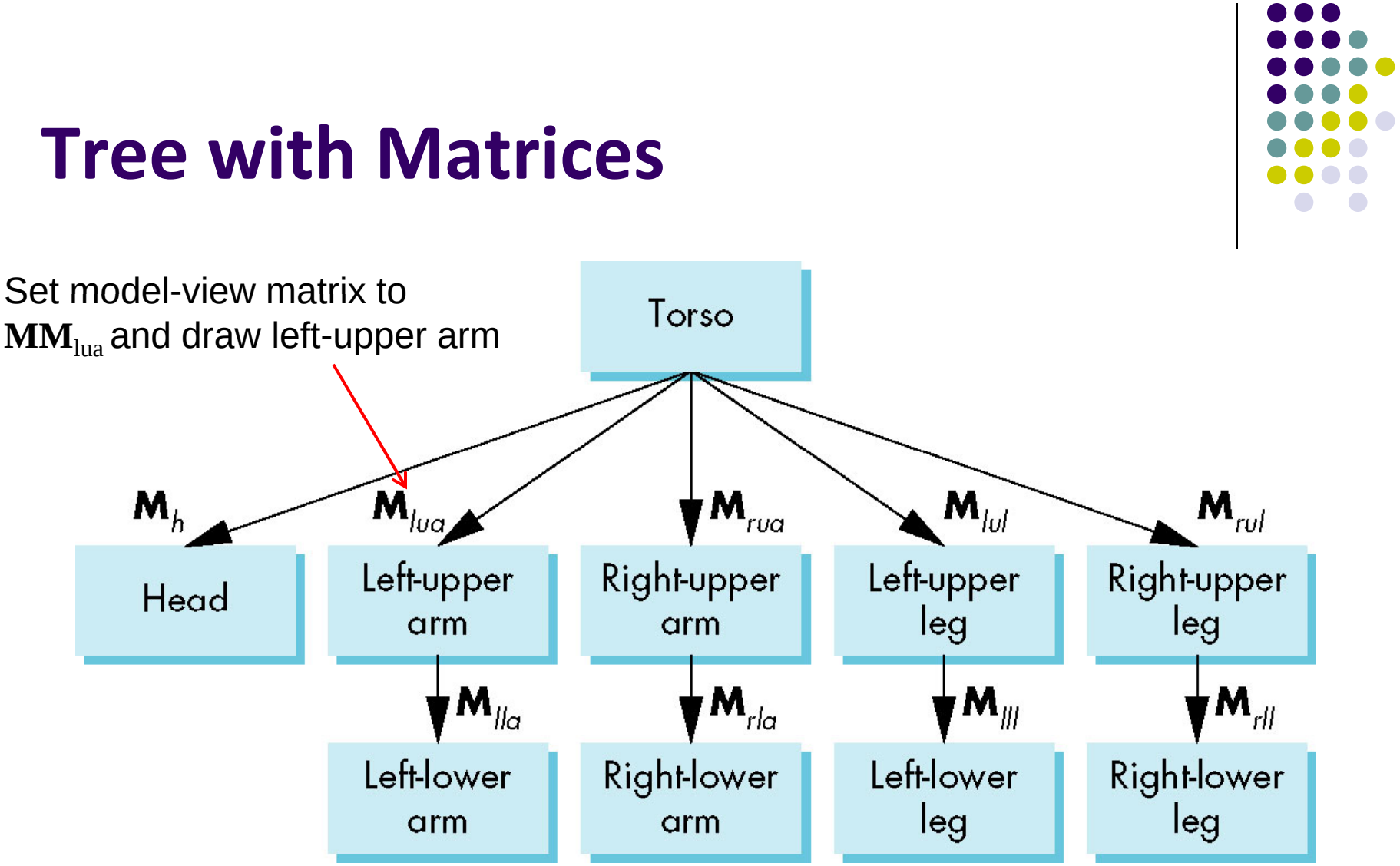
Tree with Matrices



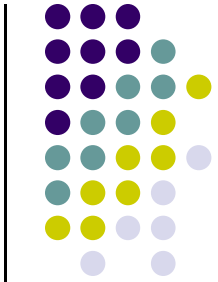
Tree with Matrices



Tree with Matrices

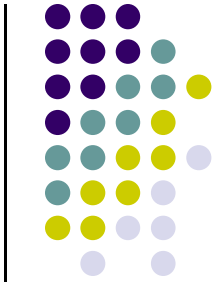


Stack-based Traversal



- We can use stack, Push, Pop for this
- Rather than recomputing $\mathbf{MM}_{\text{lua}}$ from scratch or using an inverse matrix, we can use the matrix stack to store $\mathbf{M}$ and other matrices as we traverse the tree

Traversal Code



```
figure() {
    PushMatrix()
    torso();
    Rotate (…);
    head();
    PopMatrix();
    PushMatrix();
    Translate(…);
    Rotate(…);
    left_upper_arm();
    PopMatrix();
    PushMatrix();
```

save present model-view matrix

update model-view matrix for head

recover original model-view matrix

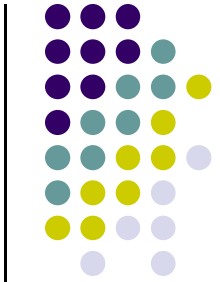
save it again

update model-view matrix for left upper arm

recover and save original model-view matrix again

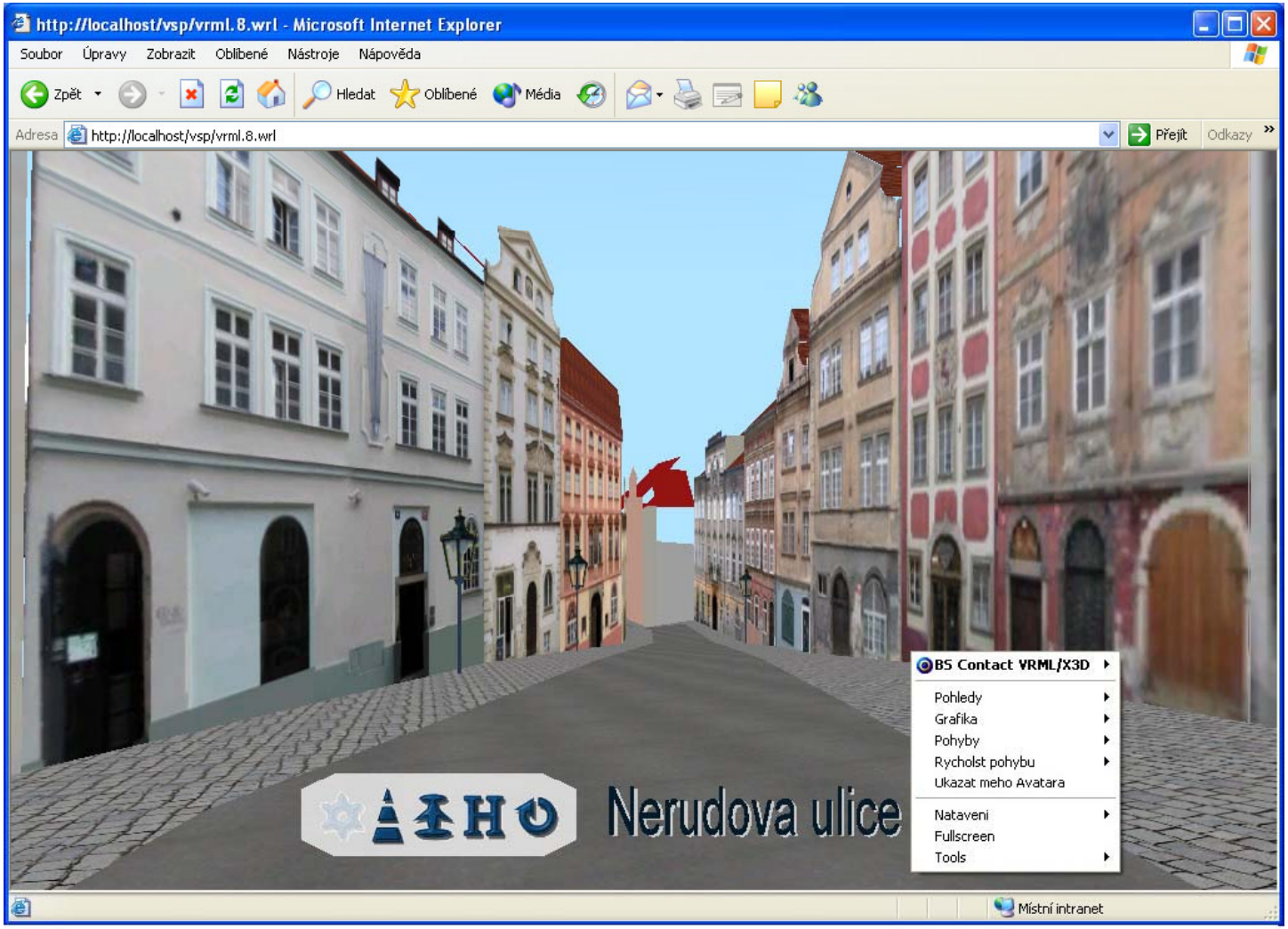
rest of code

VRML

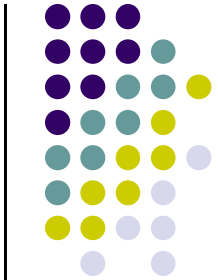


- Scene graph introduced by SGI Open Inventor
- Want to have a scene graph that can be used over the World Wide Web
- Need links to other sites to support distributed data bases
- Virtual Reality Markup Language
  - Based on Inventor data base
  - Implemented with OpenGL

VRML World Example



References



- Angel and Shreiner, Interactive Computer Graphics (6^{th} edition), Chapter 8