cs155 – z sweedyk

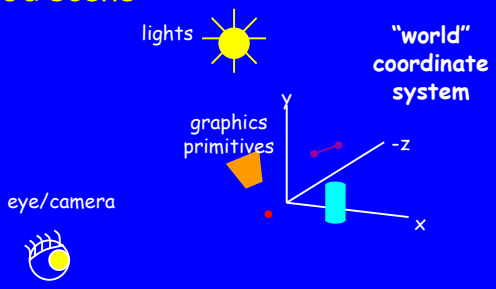
3D graphics

scene graphs

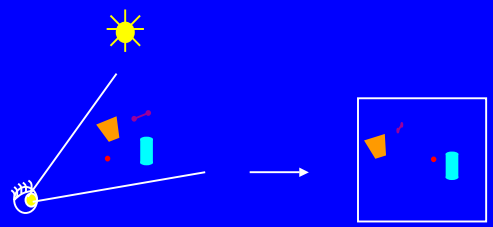
overview

- brief overview of 3D
- modeling transforms & homogenous coordinates
- hierarchical coordinates

3d scene



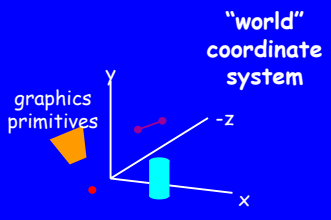
rendering



overview

- brief overview of 3D DONE
- modeling transforms & homogenous coordinates
- hierarchical coordinates

today: composing the scene

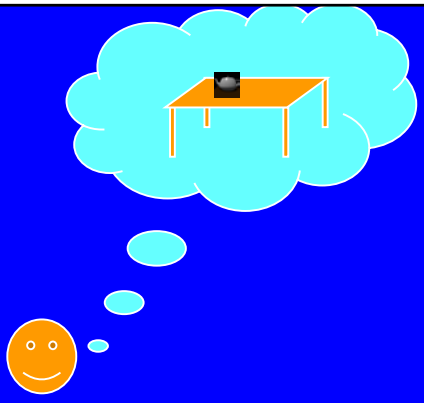


geometric primitives

- point
- line
- polygon
- curved surfaces

save this for later in the semester

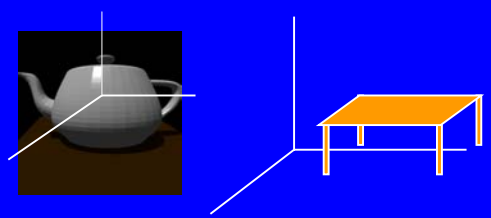
triangle mesh



3d model store

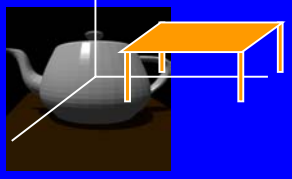
receipt
one triangle mesh teapot
one triangle mesh table

putting it together



putting it together

call Martha Stewart



making it fit

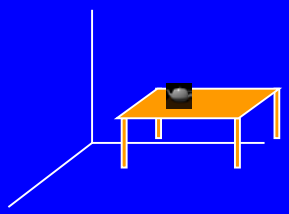
transform teapot
scale by .1
translate by (20,10,2)

making it fit

for each triangle in the teapot
scale by .1
translate by (20,10,2)

will this work?

scale and translate teapot triangles ...



now rotate it a little

transforms

- scale
- rotate
- translate

triangle

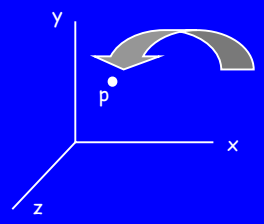
scale

rotate

translate

triangle

points



you are here!

point

call prof gu

scale

rotate

translate

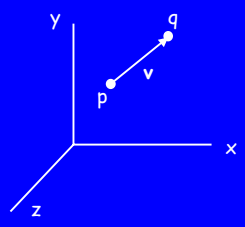
linear algebra

- scalars
- vectors

scalars: real numbers

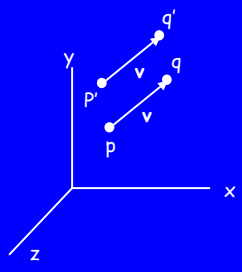
3.8
2.7
4.1
-1000.2
5

vector: distance & direction in (3d) space



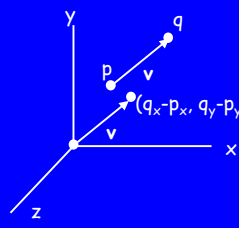
v: the way you get from p to q

vector: magnitude & direction in (3d) space



A vector does not have a position in space !

naming vectors



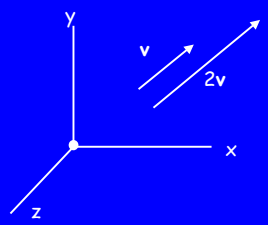
$v = \langle q_x - p_x, q_y - p_y, q_z - p_z \rangle$

$(q_x - p_x, q_y - p_y, q_z - p_z)$

linear spaces

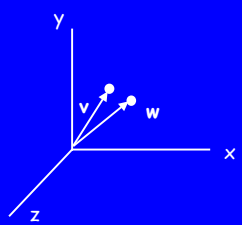
- scalars
- vectors
- scalar multiplication
- vector addition

scalar multiplication



$2v = \langle 2v_x, 2v_y, 2v_z \rangle$

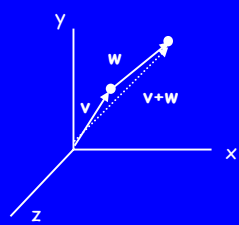
vector addition



$v = \langle v_x, v_y, v_z \rangle$

$w = \langle w_x, w_y, w_z \rangle$

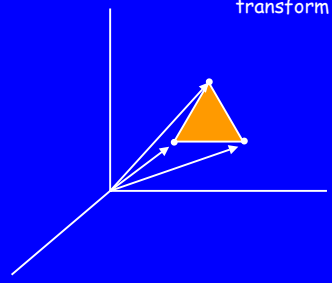
vector addition



$v+w = \langle v_x+w_x, v_y+w_y, v_z+w_z \rangle$

triangle

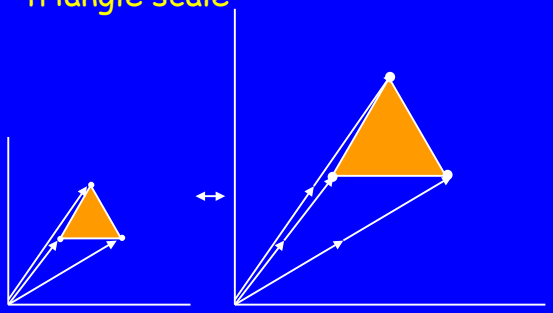
transform vectors!



triangle

scale

triangle scale



triangle scale

triangle scale

triangle scale

scale

$$\begin{pmatrix} s & 0 & 0 \\ 0 & t & 0 \\ 0 & 0 & u \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} sx \\ ty \\ uz \end{pmatrix}$$

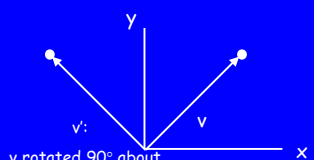
triangle

scale

rotate

translate

rotating a vector



v rotated 90° about z axis

v'= _____

rotation

$$\begin{pmatrix} \cos 90 & -\sin 90 & 0 \\ \sin 90 & \cos 90 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \begin{pmatrix} v_x \cos 90 - v_y \sin 90 \\ v_x \sin 90 + v_y \cos 90 \\ v_z \end{pmatrix}$$

rotate about z axis

$$\begin{pmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

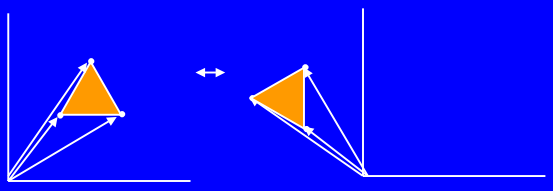
- the first column specifies what happens to (1,0,0)
- the second column specifies what happens to (0,1,0)
- the third column specifies what happens to (0,0,1)

rotation in 3D about x axis

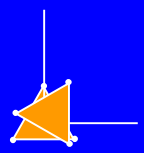
$$\begin{pmatrix} & & \\ & & \\ & & \end{pmatrix}$$

fill in the blanks

triangle rotate

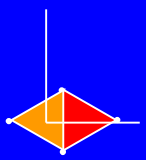


triangle rotate



triangle rotate

triangle rotate



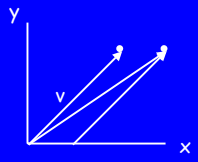
triangle

scale

rotate

translate

translating a point



p translated 2 units to the right

operators

- scale
- rotate

linear

- translate

non-linear

linear transformation

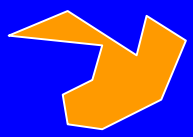
- **f(v)** is linear if
  $f(\alpha\mathbf{u}+\beta\mathbf{v}) = \alpha f(\mathbf{u})+\beta f(\mathbf{v})$
- translation is not a linear transform: define $T(v) = v+w_0$ where w_0 is a non-zero vector
  $T(u+v) = u + v + w_0$
  $T(u)+T(v) = u+v+2w_0$

composite transform

$M_1 v \longrightarrow M_2(M_1 v)$

$(M_2 M_1)v$

transform polygon mesh

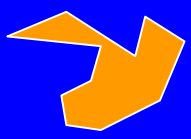


1,000,000 vertices

10 transforms

10,000,000 computations

transform polygon mesh



1,000,000 vertices

~~10 transforms~~

1 composite transform

1,000,000

~~10,000,000~~ computations

operators

- scale
- rotate

linear

- translate

non-linear

operators

- scale
- rotate

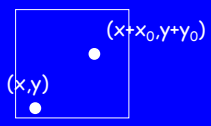
linear

- translate

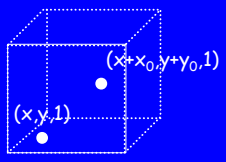
non-linear

let's step back into 2D for a moment

a little trick … 2D translate



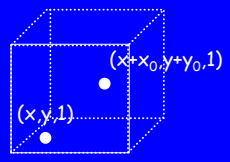
not a 2D linear xfm



3D linear xfm

a little trick … 2D translate

$$\begin{bmatrix} 1 & 0 & x_0 \\ 0 & 1 & y_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x+x_0 \\ y+y_0 \\ 1 \end{bmatrix}$$



2D homogenous coordinates

(x,y) ⟺ (x,y,1)

scale

$$\begin{bmatrix} s & 0 & 0 \\ 0 & t & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} sx \\ ty \\ 1 \end{bmatrix}$$

rotate

$$\begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x\cos\phi - y\sin\phi \\ x\sin\phi + y\cos\phi \\ 1 \end{bmatrix}$$

translate

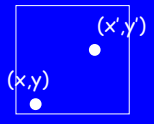
$$\begin{bmatrix} 1 & 0 & x_0 \\ 0 & 1 & y_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x+x_0 \\ y+y_0 \\ 1 \end{bmatrix}$$

transform form

$$\begin{bmatrix} ? & ? & ? \\ ? & ? & ? \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix}$$

we are not alone…

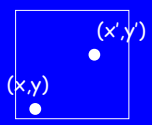
the parallel universe view of homogenous coordinates



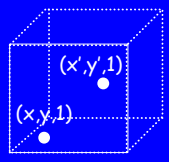
we live in this universe

we are not alone…

the parallel universe view of homogenous coordinates



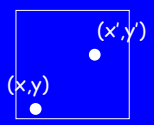
we live in this universe



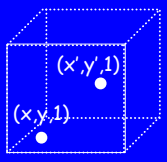
it's not the only one, but it is the only one we can experience!

and its better not to think about it …

the parallel universe view of homogenous coordinates

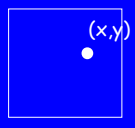


our universe has center (0,0)

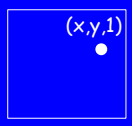


center?

2d and 2d homogenous

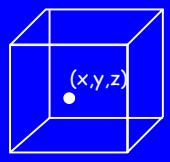


our universe

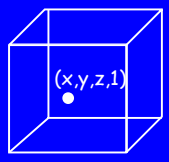


our universe when it comes to computing modeling transforms

3d and 3d homogenous



our universe



our universe when it comes to computing modeling transforms

scale

$$\begin{pmatrix} s & 0 & 0 & 0 \\ 0 & t & 0 & 0 \\ 0 & 0 & u & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} sx \\ ty \\ uz \\ 1 \end{pmatrix}$$

rotate about z axis

$$\begin{pmatrix} \cos\phi & -\sin\phi & 0 & 0 \\ \sin\phi & \cos\phi & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} x\cos\phi - y\sin\phi \\ x\sin\phi + y\cos\phi \\ z \\ 1 \end{pmatrix}$$

rotate about x & y axes are similar

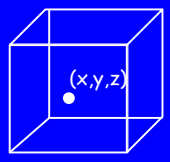
translate

$$\begin{pmatrix} 1 & 0 & 0 & x_0 \\ 0 & 1 & 0 & y_0 \\ 0 & 0 & 1 & z_0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} x+x_0 \\ y+y_0 \\ z+z_0 \\ 1 \end{pmatrix}$$

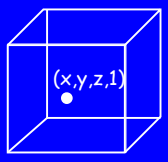
transform form

$$\begin{pmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} x' \\ y' \\ z \\ 1 \end{pmatrix}$$

3d and 3d homogenous



our universe



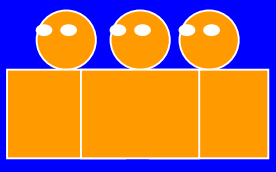
our universe when it comes to computing modeling transforms

overview

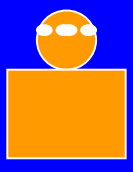
- brief overview of 3D
- modeling transforms & homogenous coordinates DONE
- hierarchical coordinates

cool action figure

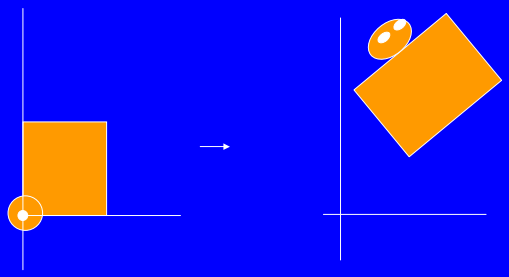
cool action figure



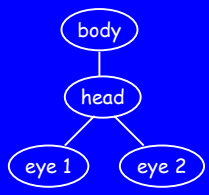
cool action figure



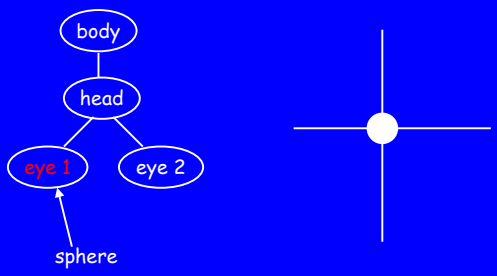
transform composition



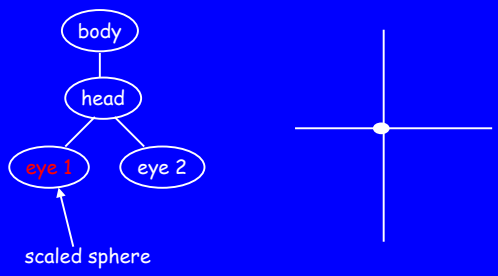
scene graph



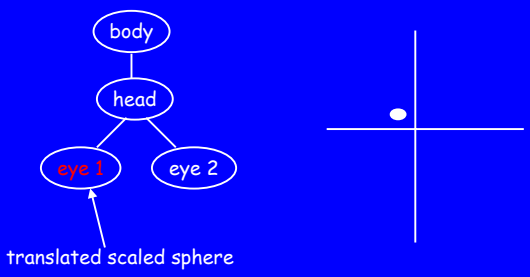
hierarchical coordinates



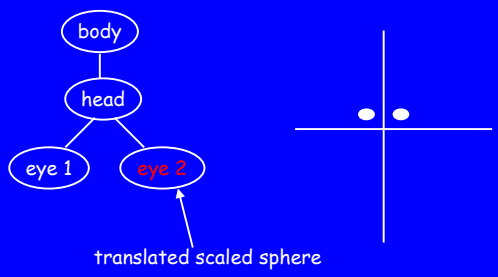
hierarchical coordinates



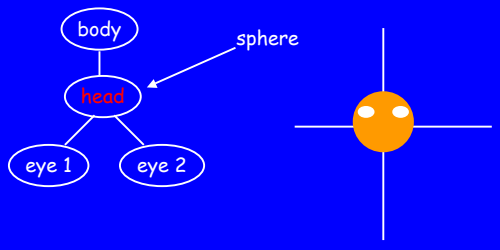
hierarchical coordinates



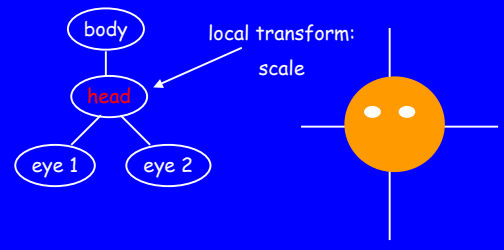
hierarchical coordinates



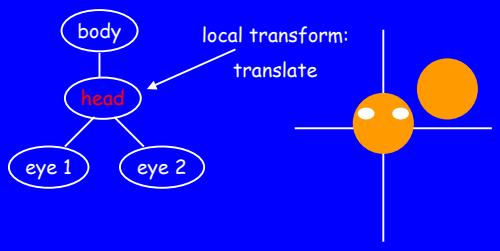
hierarchical coordinates



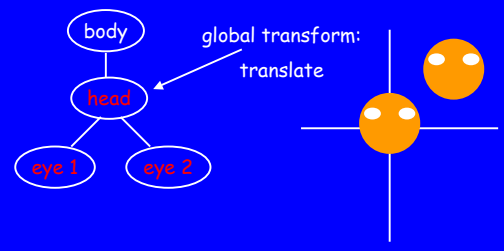
hierarchical coordinates



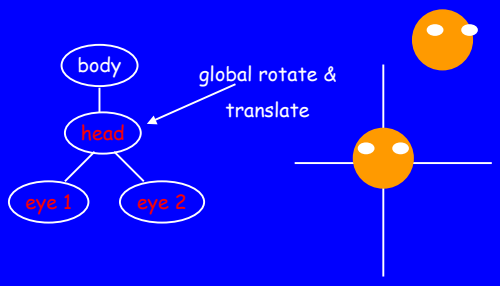
hierarchical coordinates



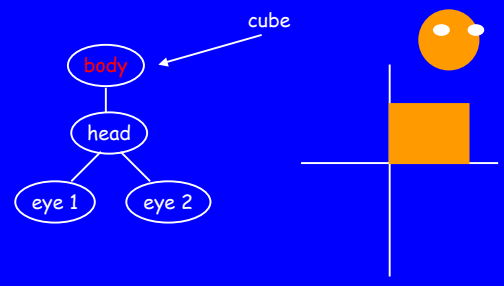
hierarchical coordinates



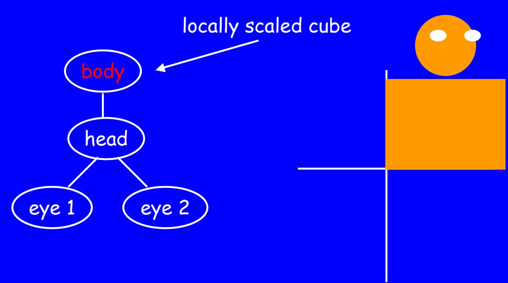
hierarchical coordinates



hierarchical coordinates

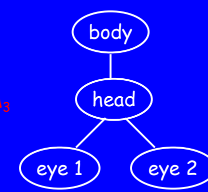


hierarchical coordinates



the transforms

body xfm M_1
{local body scale M_1M_2
body description draw
}
M_1
head translate wrt body M_1M_3
head rotate
head description
{eye1 translate wrt head
eye1 scale
eye1 description}
{eye2 translate wrt head
eye2 scale
eye2 description}



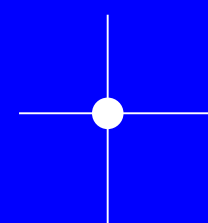
hierarchical coordinates

body xfm
{local body scale
body description}
head translate wrt body
head rotate
head description
{eye1 translate wrt head
eye1 scale
eye1 description}
{eye2 translate wrt head
eye2 scale
eye2 description}

more intuitive to specify transforms in reverse order

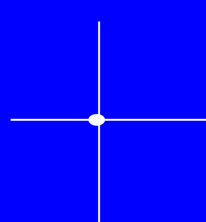
hierarchical coordinates

body xfm
{local body scale
body description}
head translate wrt body
head rotate
head description
{eye1 translate wrt head
eye1 scale
eye1 description}
{eye2 translate wrt head
eye2 scale
eye2 description} ←



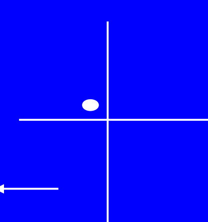
hierarchical coordinates

body xfm
{local body scale
body description}
head translate wrt body
head rotate
head description
{eye1 translate wrt head
eye1 scale
eye1 description}
{eye2 translate wrt head
eye2 scale ←
eye2 description}



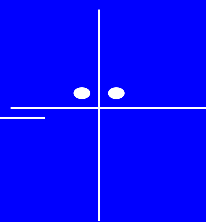
hierarchical coordinates

body xfm
{local body scale
body description}
head translate wrt body
head rotate
head description
{eye1 translate wrt head
eye1 scale
eye1 description}
{eye2 translate wrt head ←
eye2 scale
eye2 description}



hierarchical coordinates

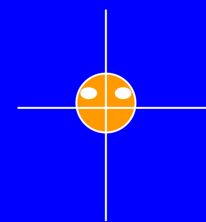
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



9/17/2003

hierarchical coordinates

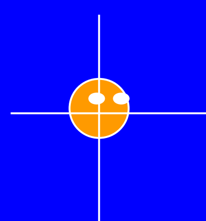
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



9/17/2003

hierarchical coordinates

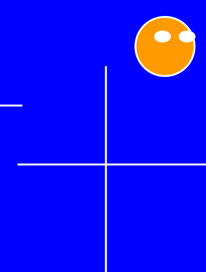
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



9/17/2003

hierarchical coordinates

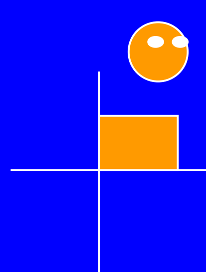
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



9/17/2003

hierarchical coordinates

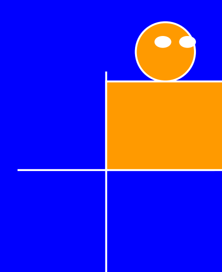
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



9/17/2003

hierarchical coordinates

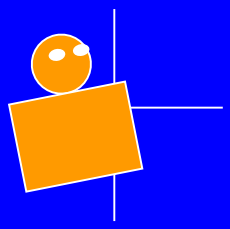
body xfm
{local body scale
body description}
  head translate wrt body
  head rotate
  head description
    {eye1 translate wrt head
    eye1 scale
    eye1 description}
    {eye2 translate wrt head
    eye2 scale
    eye2 description}



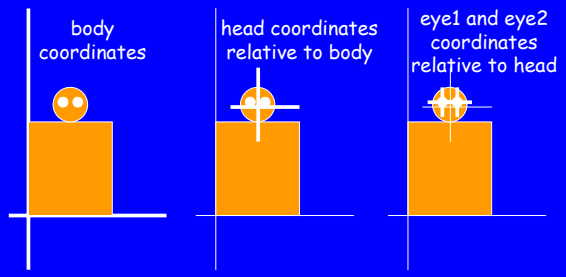
9/17/2003

hierarchical coordinates

body xfm
{local body scale
body description}
    head translate wrt body
    head rotate
    head description
        {eye1 translate wrt head
        eye1 scale
        eye1 description}
        {eye2 translate wrt head
        eye2 scale
        eye2 description}

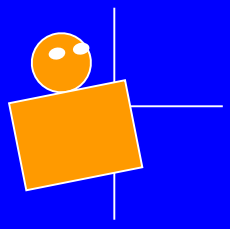


hierarchical coordinates

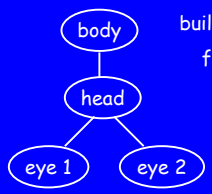


now nod

body xfm
{local body scale
body description}
    head translate wrt body
    head rotate
rotate head description
        {eye1 translate wrt head
        eye1 scale
        eye1 description}
        {eye2 translate wrt head
        eye2 scale
        eye2 description}



scene graph



build a scene graph for a snowman

snowman scene graph

- sphere: radius 1 drawn with center at origin
- cylinder: radius 1 and height 1 sitting on the origin
- cone: bottom radius 1 and height 1 sitting at the origin
- scale (s,t,u)
- rotate (theta, vector)
- translate (dx,dy,dz)