

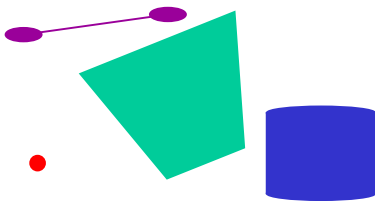
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constituents of 3d scene

3d graphics

- Modeling
- Rendering

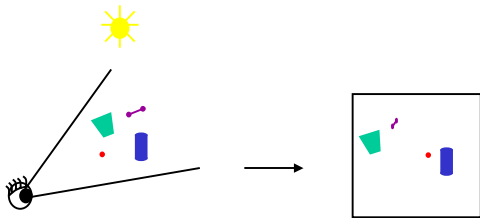
modeling



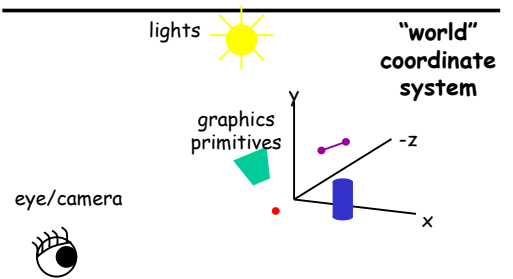
triangle mesh



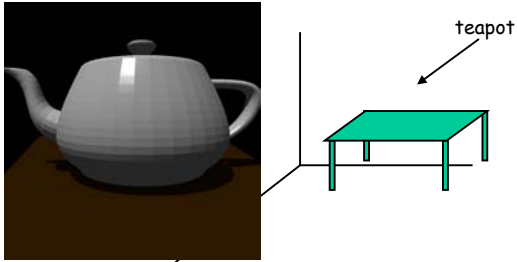
rendering



3d scene



putting it together



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transforms

- scale
- rotate
- translate

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triangle

scale



rotate



translate



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triangle

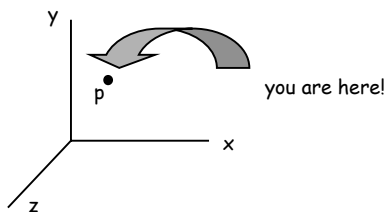


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points



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point

scale



rotate



translate



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linear spaces

- scalars
- vectors

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scalars: real numbers

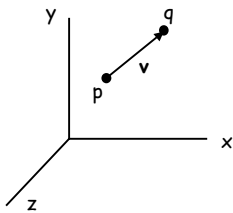
3.8
2.7
4.1
-1000.2
5

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vector: distance & direction in (3d) space



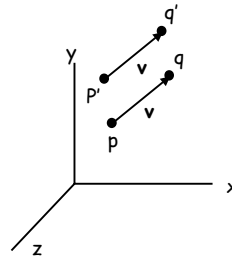
v: the way you get from p to q

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vector: magnitude & direction in (3d) space



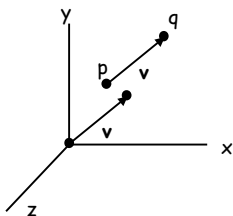
A vector does not have a position in space !

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naming vectors



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

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linear spaces

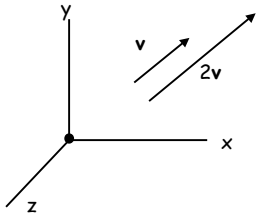
- scalars
- vectors
- scalar multiplication
- vector addition

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scalar multiplication



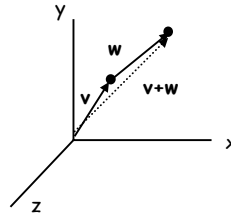
$$2v = \langle 2v_x, 2v_y, 2v_z \rangle$$

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vector addition



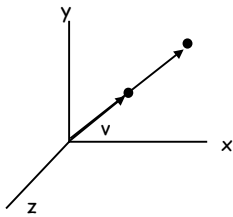
$$v+w = \langle v_x+w_x, v_y+w_y, v_z+w_z \rangle$$

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scaling a point



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

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scale

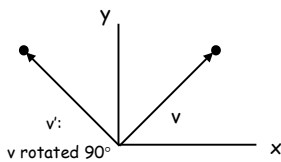
$$\begin{pmatrix} s & 0 & 0 \\ 0 & t & 0 \\ 0 & 0 & u \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} sx \\ ty \\ uz \end{pmatrix}$$

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rotating a point



$$v' = \underline{\hspace{2cm}}$$

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rotation

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

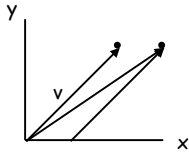
(can do it in 3d too)

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translating a point



p translated 2 units to the right

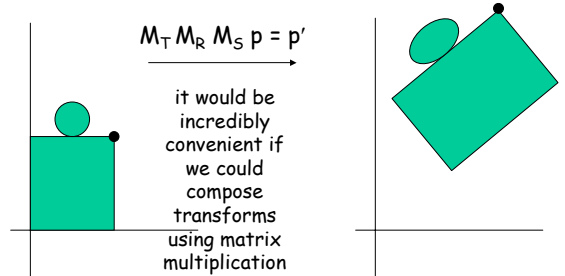
operators

- scale } linear
- rotate } linear
- translate non-linear

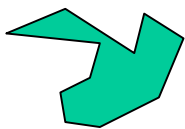
linear transformation

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

transform composition



transform polygon mesh

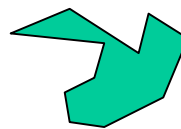


1,000,000 vertices
10 transforms



10,000,000 computations

transform polygon mesh



1,000,000 vertices
~~10 transforms~~

1 composite transform

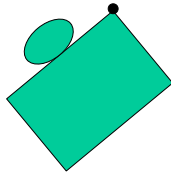


1,000,000
~~10,000,000~~ computations

transform composition

$$M_T M_R M_S p = p'$$

it would be
incredibly
convenient if
we could
compose
transforms
using matrix
multiplication

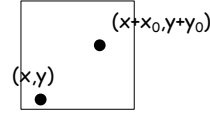


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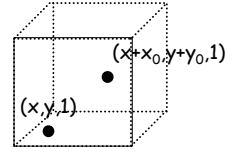
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a little trick ...



not a linear xfm



linear xfm

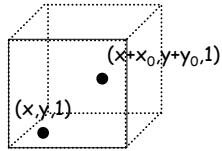
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a little trick ...

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



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homogenous coordinates

$$(x, y) \longleftrightarrow (x, y, 1)$$

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scale

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

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rotate

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

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translate

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

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transform form

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

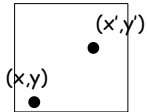
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we are not alone...

the parallel universe view of homogenous coordinates



we live in this universe

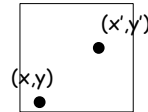
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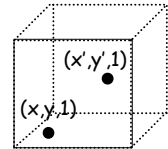
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we are not alone...

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!

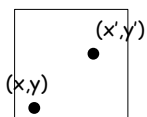
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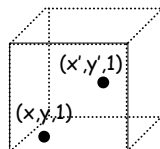
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and its better not to think about it ...

the parallel universe view of homogenous coordinates



our universe has center (0,0)



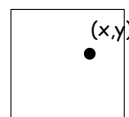
center?

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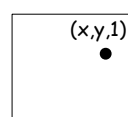
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2d and 2d homogenous



our universe



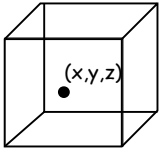
our universe when it comes to computing modeling transforms

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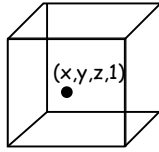
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3d and 3d homogenous



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

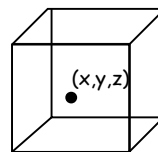
translate

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

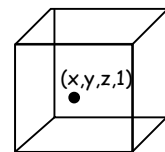
transform form

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

3d and 3d homogenous

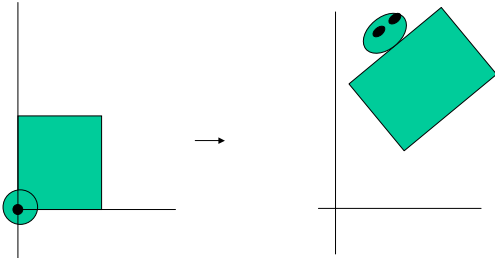


our universe



our universe when
it comes to
computing modeling
transforms

transform composition

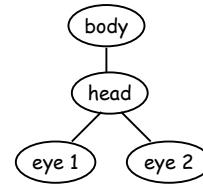


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scene graph



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hierarchical coordinates

body xfm
 body description
 head translate wrt body
 head rotate
 head description
 eye1 translate wrt head
 eye1 scale
 eye1 description

↑
order of operations

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hierarchical coordinates

body xfm
 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} ←

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hierarchical coordinates

body xfm
 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}

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hierarchical coordinates

body xfm
 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}

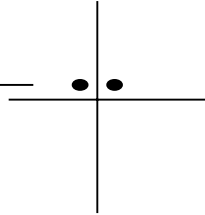
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hierarchical coordinates

```
body xfm
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}
```



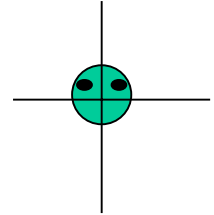
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hierarchical coordinates

```
body xfm
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}
```



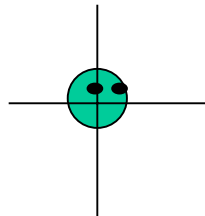
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hierarchical coordinates

```
body xfm
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}
```



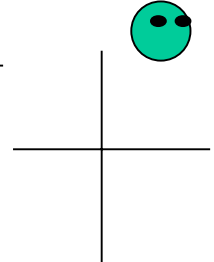
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hierarchical coordinates

```
body xfm
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}
```



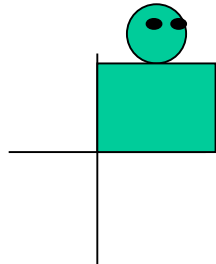
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hierarchical coordinates

```
body xfm ←
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}
```



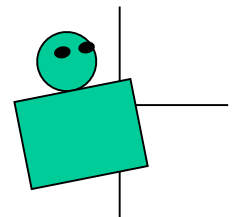
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hierarchical coordinates

```
body xfm ←
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}
```



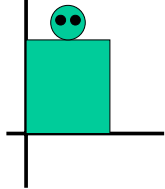
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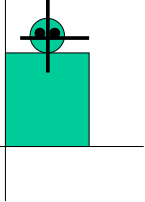
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hierarchical coordinates

body
coordinates



head coordinates
relative to body



eye1 and eye2
coordinates
relative to head

