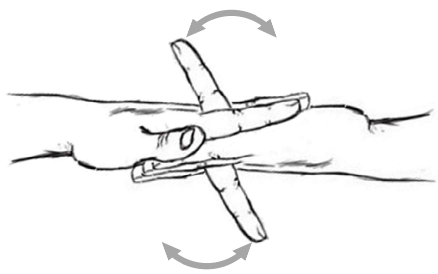
3D VideoGames
Unimi

# Animations in games

Marco Tarini



1

## Course Plan

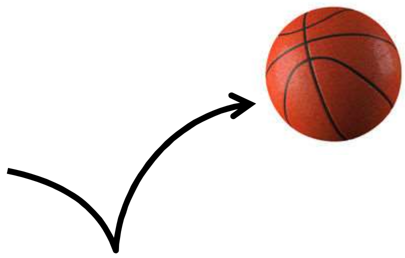
- lec. 1: Introduction
- lec. 2: Mathematics for 3D Games
- lec. 3: Scene Graph
- lec. 4: Game 3D Physics +
- lec. 5: Game Particle Systems
- lec. 6: Game 3D Models
- lec. 7: Game Textures
- lec. 8: Game 3D Animations
- lec. 9: Game Materials
- lec. 10: 3D Audio for 3D Games
- lec. 11: Networking for 3D Games
- lec. 12: Artificial Intelligence for 3D Games
- lec. 13: Rendering Techniques for 3D Games

3

## Computer animation in games

1. of rigid objects
   - animate scene transformations

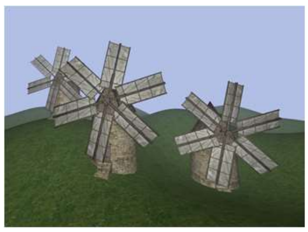


(6 DoF per object)

5

## Computer animation in games

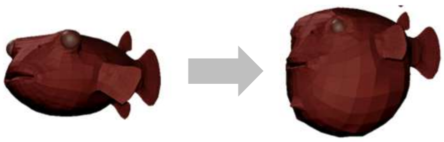
1. of rigid objects
   - or objects made of rigid sub-parts



6

# Computer animation in games

2. Free-Form deformations
   - generic transformations of the object

7

# Computer animation in games

3. of articulated models
   - internal skeleton
   - most virtual characters!
   - "skinning"

8

## Types of animation and DoF (per keyframe)

DoF = Degrees of Freedom

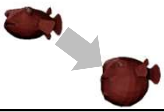
Rigid

6 DoF per object
(or, e.g., 9, with anisotropic scaling)

Articulated

~50-100 DoF per object
(e.g. 3 DoF per joint x 25 joints)

Free form



300-10.000 DoF per object
(e.g. 3 per-vertex)

9

## Summary: Types of authored animations

- of objects made of rigid subparts
  - including joints: robots, cars…
  - → use "(forward) kinematics animations"
    (scripted changes of the modelling transforms)
- of deformable articulated objects
  - with some internal skeleton
  - e.g: most virtual characters:
    humans / animals / monsters
  - → use "skinning" / "rigging"
- of generic deformable objects ("soft bodies")
  - e.g., human faces, an umbrella opening, stuff with membrane…
  - → use "blend shapes"

10

## Animations in games

**Authored** ⟵ ⟶ **Procedural**

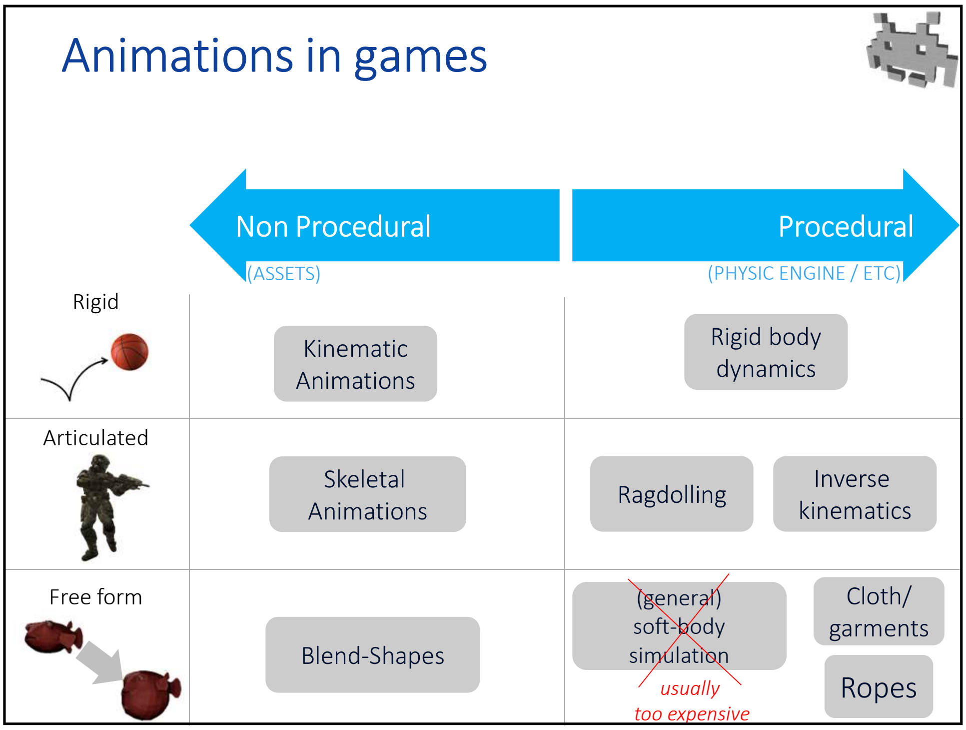
| Authored | Procedural |
|---|---|
| Assets! | Physic engine |
| Control: easy. full control by artists (e.g. for dramatic effect) | Control: hard |
| Realism: hard it's up to the artist skill | Realism: easy built-in physical laws |
| Flexibility: little Doesn't adapt to env. | Flexibility: great Adapts to env. / context |
| (consumes RAM) | (consumes GPU) |

11

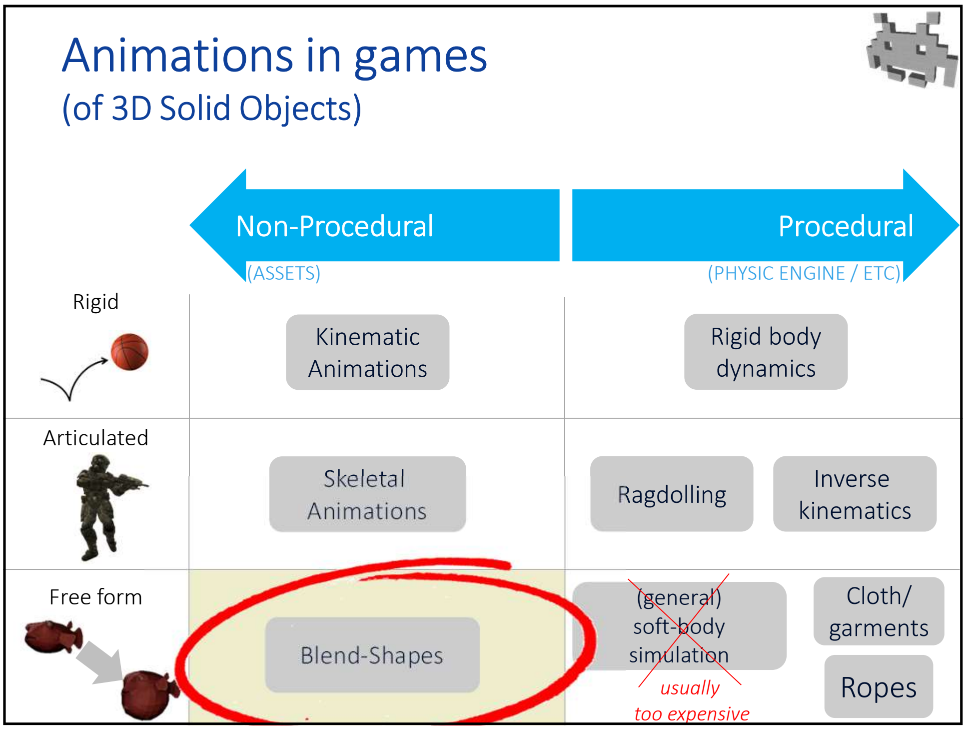
## Animations in games: authored, procedural... or a mix?

- A few examples of current commonly used mixes:
  1: *"primary"* animations: authored
  *"secondary"* animations: physically generated
  2: *alive* characters: authored
  *dead* characters: physically generated ("ragdolls")
  3: walk cycle: authored (skeletal animation)
  exact *feet placement*: procedural (inverse kinematic)
  4: normal "behavior", such as sparring: authored
  *gaze control* during sparring: procedural
  5: normal "behaviors" such as jumping, running: authored
  modifications / transitions: AI generated
  and more!
- mixing AI-generated with authored animations is a frontier in the field of Computer Animation!

12


Animations in games
Non Procedural
(ASSETS)
Procedural
(PHYSIC ENGINE / ETC)
Rigid
Kinematic Animations
Rigid body dynamics
Articulated
Skeletal Animations
Ragdolling
Inverse kinematics
Free form
Blend-Shapes
(general) soft-body simulation
usually too expensive
Cloth/ garments
Ropes

14


Animations in games
(of 3D Solid Objects)
Non-Procedural
(ASSETS)
Procedural
(PHYSIC ENGINE / ETC)
Rigid
Kinematic Animations
Rigid body dynamics
Articulated
Skeletal Animations
Ragdolling
Inverse kinematics
Free form
Blend-Shapes
(general) soft-body simulation
usually too expensive
Cloth/ garments
Ropes

15

## Asset for free-form animations: Blend-shapes

- A.K.A:
  - Blend-shapes
  - Per-vertex animations
  - Vertex-animations
  - Face-morphs
  - Shape-keys
  - Morph-targets
  - …

BARRY BLITT (THE NEW YORKER)

16

## Blend shapes: concept

Walk cycle
(Monkey Island
LucasArt 1991)

- Animation in 2D (old school) games:
  a sequence of sprites
- Animation in 3D games:
  just a sequence of meshes?

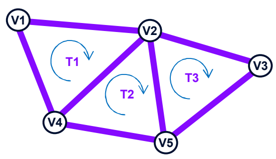
17

## Reminder: representation of a mesh

- Indexed mode :
  - Geometry:
    - a 3D position for each vertex
  - Attributes:
    - more data, also stored in each vertex
    - (to be interpolated inside faces)
  - Connectivity:
    - Array of triangles (faces)
    - Each triangle = a triplet of indexes to vertex

18

## Mesh (data structure)




*connectivity (indexed)*

| Tri: | Wedge 1: | Wedge 2: | Wedge 3: |
|---|---|---|---|
| T1 | V4 | V1 | V2 |
| T2 | V4 | V2 | V5 |
| T3 | V5 | V2 | V3 |

*geometry:*

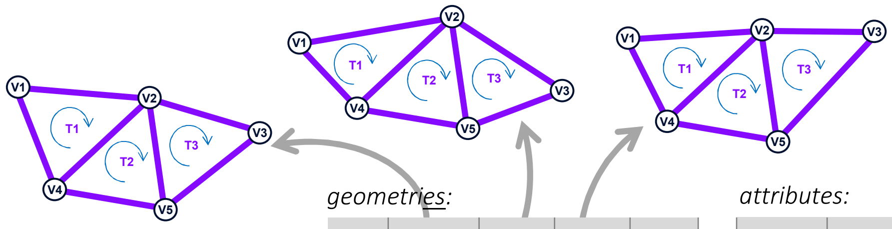
| Vert: | Pos |
|---|---|
| V1 | $(x, y, z)$ |
| V2 | $(x, y, z)$ |
| V3 | $(x, y, z)$ |
| V4 | $(x, y, z)$ |
| V5 | $(x, y, z)$ |

*attributes:*

| UV | Col |
|---|---|
| $(u, v)$ | $(r, g, b)$ |
| $(u, v)$ | $(r, g, b)$ |
| $(u, v)$ | $(r, g, b)$ |
| $(u, v)$ | $(r, g, b)$ |
| $(u, v)$ | $(r, g, b)$ |

19

# Blend shapes (data structure)




*geometries:*

| Vert: | Base Shape | Shape 1 | Shape 2 | ... |
|---|---|---|---|---|
| V1 | $(x,y,z)$ | $(x,y,z)$ | $(x,y,z)$ | ... |
| V2 | $(x,y,z)$ | $(x,y,z)$ | $(x,y,z)$ | ... |
| V3 | $(x,y,z)$ | $(x,y,z)$ | $(x,y,z)$ | ... |
| V4 | $(x,y,z)$ | $(x,y,z)$ | $(x,y,z)$ | ... |
| V5 | $(x,y,z)$ | $(x,y,z)$ | $(x,y,z)$ | ... |

*attributes:*

| UV | Col |
|---|---|
| $(u,v)$ | $(r,g,b)$ |
| $(u,v)$ | $(r,g,b)$ |
| $(u,v)$ | $(r,g,b)$ |
| $(u,v)$ | $(r,g,b)$ |
| $(u,v)$ | $(r,g,b)$ |

*connectivity (indexed)*

| Tri: | Wedge 1: | Wedge 2: | Wedge 3: |
|---|---|---|---|
| T1 | V4 | V1 | V2 |
| T2 | V4 | V2 | V5 |
| T3 | V5 | V2 | V3 |

20

# Blend shapes

- A mesh with several associated geometries
- I.e. a sequence of meshes ('shapes') with
  - shared connectivity
  - many shared attributes
    - except normals / tangents dirs
    - shared UV-map, per vertex colors…
  - different geometries
  - (and shared textures as well)

aka 'morph'
aka (key)-'frame'
aka 'shape-key'

- Variants (they are equivalent):
  - Relative mode:
    - *base shape*: stored as per-vertex positions (points)
    - any other *shape*: stored as difference with *base shape* (vectors)
  - Absolute mode:
    - each *shape* stored as per-vertex positions (points)

21

## Blend shapes
(as a data structure, e.g. C++)

- Indexed mesh :

```
class Vertex {
  vec3 pos;
  rgb color;
  vec3 normal;
};

class Face{
   int vertexIndex[3];
};

class Mesh{
  vector<Vertex> vert; /* geom + attr */
  vector<Face> tris;   /* connectivity */
};
```

22

## Blend shapes
(as a data structure, e.g. C++)

- Blend-shape :

```
class Vertex {
  vec3 pos [ N_SHAPES ] ;
  rgb color;
  vec3 normal [ N_SHAPES ] ;
};

class Face{
   int vertexIndex[3];
};

class Mesh{
  vector<Vertex> vert; /* geom + attr */
  vector<Face> tris;   /* connectivity */
};
```

23

## Blend-shapes: most common interchange formats

- Simple:
  - .MD5 (“quake”, valve)
  - or, just store a sequence of meshes (es .OBJ)
    - making sure connectivity is coherent!
      (vertex, face ordering must be the same – can be tricky)
- Complex:
  - .DAE (Collada)
  - .FBX (Autodesk)

24

## Uses of Blend-Shapes: facial expressions

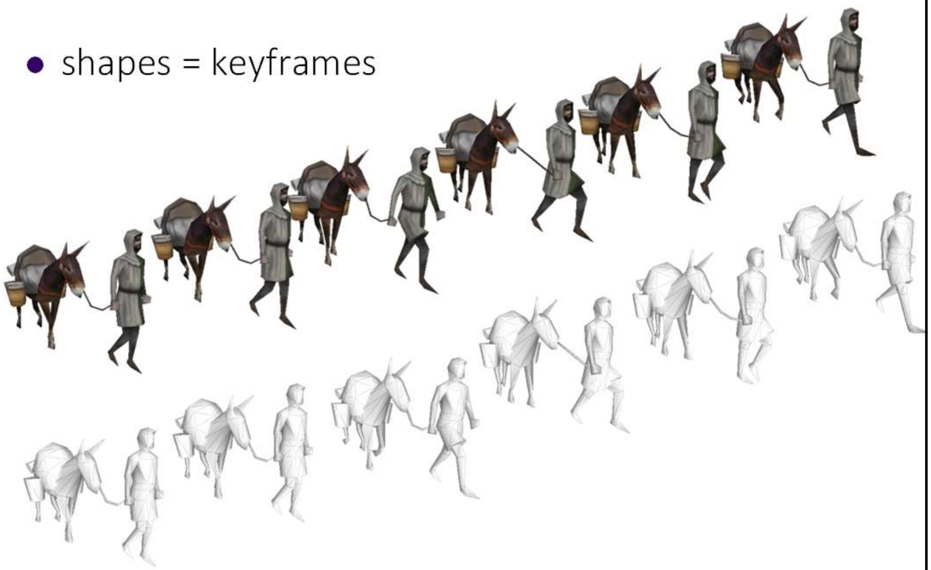
shape A shape B

here: shapes = facial expressions
(typical use; that’s why they are also called “face morphs”

25

## Uses of Blend shapes: temporal sequences

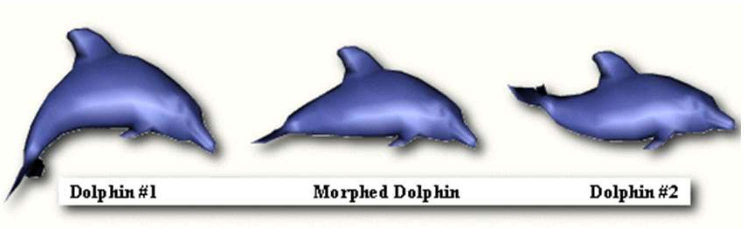
- shapes = keyframes



26

## Uses of Blend shapes: temporal sequences

- Temporal sequences
  - shapes = keyframes




27

## Blending keyframes of a temporal sequence

- shapes = keyframes of the animation
  - shape$_A$  with time $t_A$
  - shape$_B$  with time $t_B$
  - shape$_C$  with time $t_C$
  - shape$_D$  with time $t_D$
- given current time $t$ with $t_B \le t \le t_C$
- *then…*
  - which shapes to blend? shape$_B$ , shape$_C$
  - weights? $w_B = \frac{t - t_C}{t_B - t_C}$ $w_C = (1 - w_B) = \frac{t - t_B}{t_C - t_B}$

28

## Blending keyframes of a temporal sequence with transition functions

- shapes = keyframes of the animation
  - shape$_A$  with time $t_A$
  - shape$_B$  with time $t_B$
  - shape$_C$  with time $t_C$
  - shape$_D$  with time $t_D$
- given current time $t$ with $t_B \le t \le t_C$
- *then…* *transition function*
  - which shapes to blend? shape$_B$ , shape$_C$
  - weights? $w_B = \boldsymbol{f}\left(\frac{t - t_C}{t_B - t_C}\right)$ $w_C = (1 - w_B)$

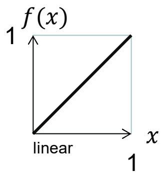
29

Marco Tarini
Università degli studi di Milano

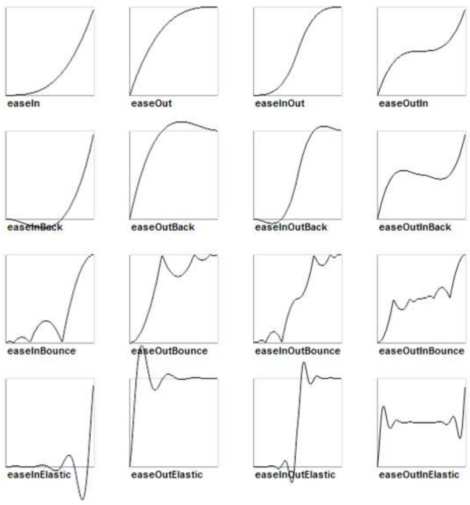
 

## Transition functions
(applies to all animation types with keyframes)

- Not necessarily the Linear one



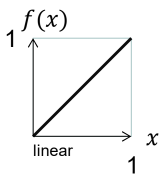

$f(x) = x$




30

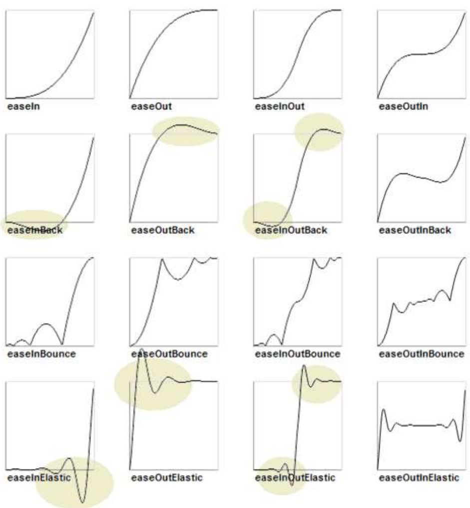
## Transition functions
(applies to all animation types with keyframes)

- Not necessarily the Linear one




$f(x) = x$

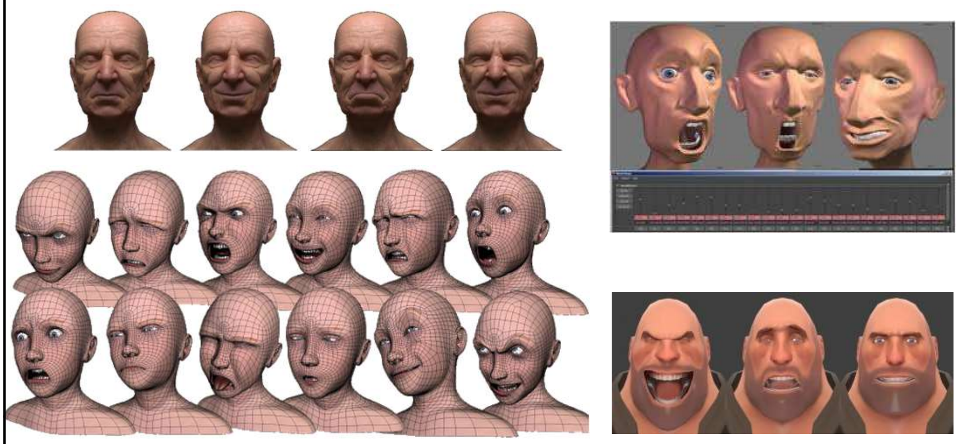
NB: = extrapolation !
i.e. exaggeration




31

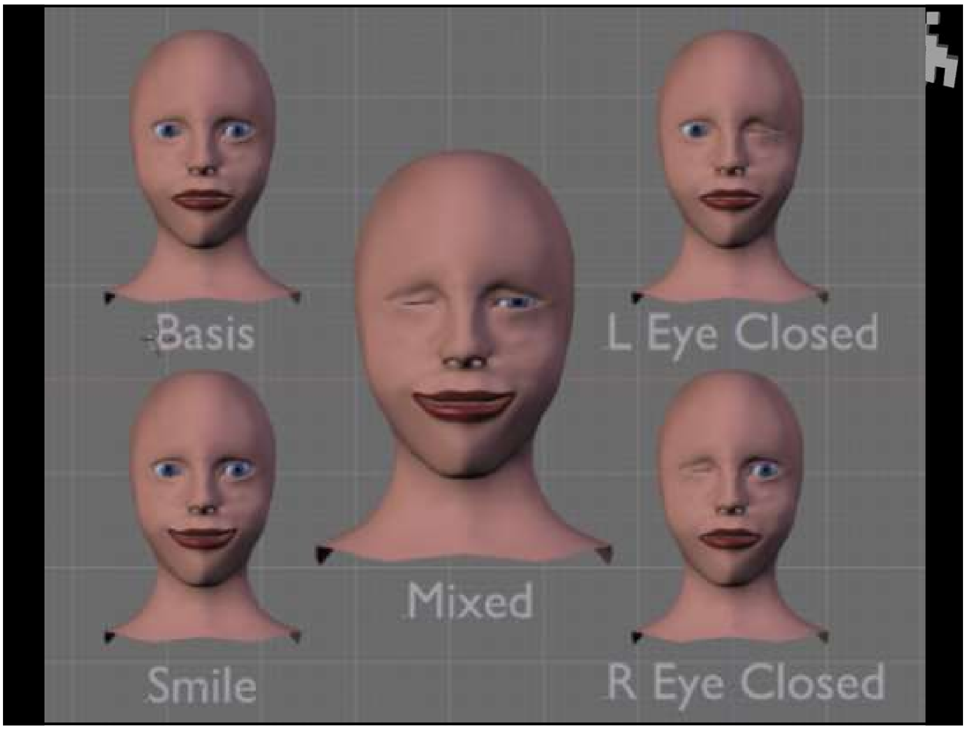
 

## Uses of Blend shapes: facial animations



Here, used together with skeletal animations (see next lecture)
(for mandible, neck, eyeballs)

34




35

## Blending shapes of a blend-shape

| | | | |
|---|---|---|---|
| What is stored | | base shape (positions), shapes (positions): $S_b\,,\underbrace{S_0}_{S_b+R_0}\,,\underbrace{S_1}_{S_b+R_1}\,,S_2\,\ldots$ | base shape (positions), shapes (vectors): $S_b\,,\underbrace{R_0}_{S_0-S_b}\,,\underbrace{R_1}_{S_1-S_b}\,,R_2\,\ldots$ |
| Equivalent ways to blend… | two shapes $i$ and $j$ | $w_i\,S_i + w_j S_j$ | $S_b + w_i\,R_i + w_j R_j$ |
| | three shapes $i,j$ and $k$ | $w_i\,S_i + w_j\,S_j + w_k\,S_k$ | $S_b + w_i\,R_i + w_j\,R_j + w_k\,R_k$ |
| | etc | | |
| $\Sigma w = 1$ | | using Absolute Encoding | using Relative Encoding |

36

## Blending shapes of a blend-shape

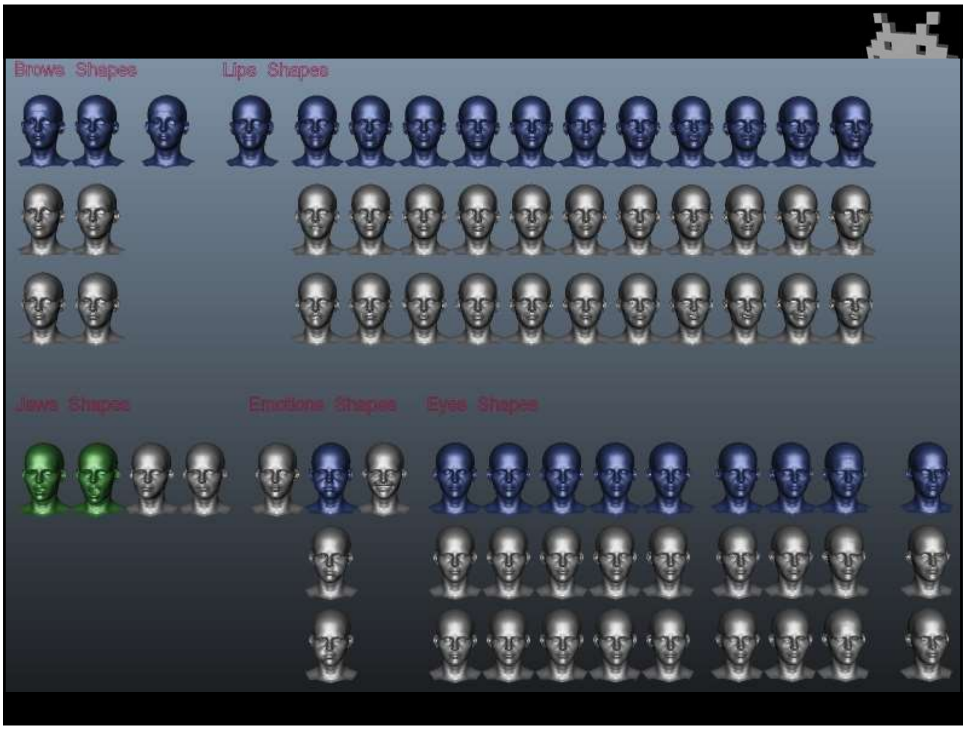
| | | | |
|---|---|---|---|
| What is stored | | base shape (positions), shapes (positions): $S_b\,,\underbrace{S_0}_{S_b+R_0}\,,\underbrace{S_1}_{S_b+R_1}\,,S_2\,\ldots$ | base shape (positions), shapes (vectors): $S_b\,,\underbrace{R_0}_{S_0-S_b}\,,\underbrace{R_1}_{S_1-S_b}\,,R_2\,\ldots$ |
| Equivalent ways to blend… | base shape with one shape $i$ | $(1-w)S_b + w\,S_i$ | $S_b + w\,R_i$ |
| | base shape with two shapes $(i,j)$ | $(1-w_i-w_j)S_b + {}$ $+\,w_i\,S_i + w_j\,S_j$ | $S_b + w_i\,R_i + w_j\,R_j$ |
| | base shape with three shapes | $(1-w_i-w_j-w_k)S_b +$ $w_i\,S_i + w_j\,S_j + w_k\,S_k$ | $S_b + w_i\,R_i + w_j\,R_j + w_k\,R_k$ |
| $\cancel{\Sigma w = 1}$ | | using Absolute Encoding | using Relative Encoding |

37

## Blending shapes of a blend-shape: notes

- The two ways to store a bland-shape are equivalent
  - They can achieve the same set of morphed shapes
  - Note: when $\Sigma w_i$=1 the formula for absolute is simpler
  - Note: when $\Sigma w_i$>1 it becomes an extrapolation (beware)
- The absolute way is more natural when shapes are designed to be used as *alternatives* (and $\Sigma w_i$=1 )
  - Examples: keyframes of an animation sequence
- The relative way is more natural when shapes are designed to be *superimposed* with various degrees of strength. E.g.:
  - $\text{shape}_0$ = close left eye
  - $\text{shape}_1$ = smile
  - $\text{shape}_0$ + $\text{shape}_1$ = wink
  - $\text{shape}_0$ = fat
  - $\text{shape}_1$ = long chin
  - 0.4 $\text{shape}_0$ + 0.9 $\text{shape}_1$ = a bit fat & quite long chin

38




42

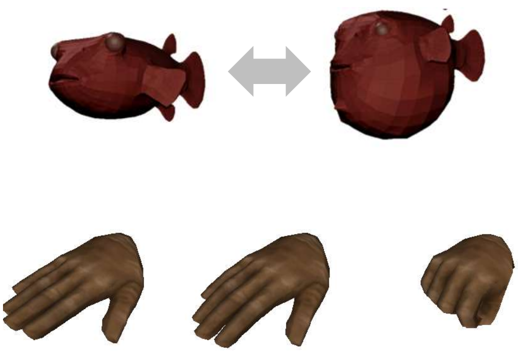
## Using facial animations as Blend shapes

- 3D Modeller authors:
  produces the blend-shapes (aka: the “facial rig”)
- Animator (of expressions) picks:
  weights
  - eg.: with sliders
  - assisted / substituted by automatisms
    - e.g., lip sync
    - e.g., dynamically determined expressions
- Keyshape Blending: by rendering engine

43

## Uses of Blend-Shapes: generic deformations

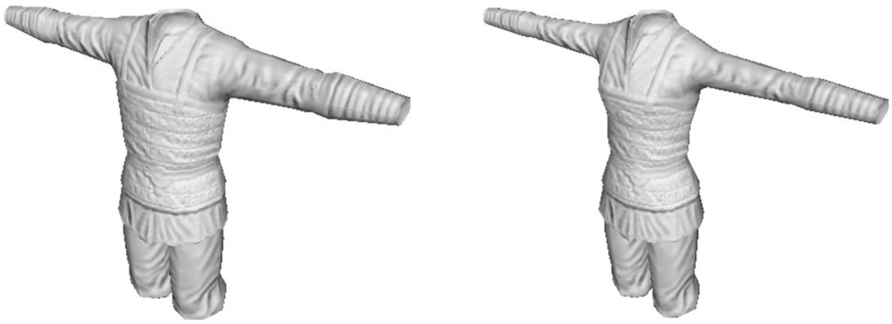
- Baked poses



44

## Uses of Blend-Shapes: variants of one given object

- mixable!



*masculine outfit* *feminine outfit*

45

## Uses of Blend-Shapes variants of one given object

- mixable!

*human* *orc* *goblin* *dwarf*

46

Marco Tarini
Università degli studi di Milano

## Uses of Blend-Shapes

- Defines shapes of a class of objects
  - get a shape in the class = just choose the weights
    - 3D modelling at a high-level of abstraction
  - the weights "span" one shape space
    - one given shape = one point in the space
    - weights = coords
  - the space is the more useful the more:
    - *all and only* the reasonable shapes
      are represented in the space
- Typical Example: face morphologies
  - "face-space"
  - note: face morphology ≠ facial expression

47

## Uses of Blend shapes

- A blend shape modelling a face space ("face-morphs")

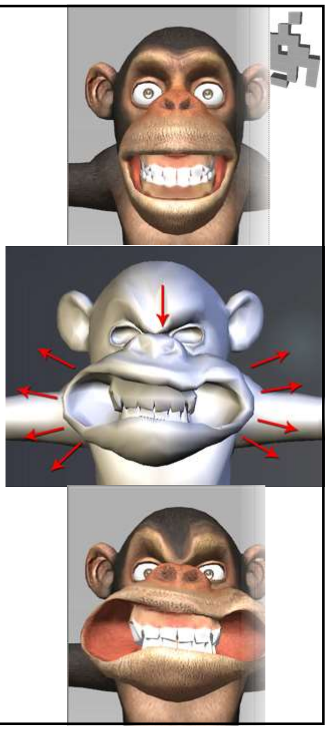
48

## All morph-shape share… (so, a blend-shape *cannot* change)…

- The mesh connectivity
  - Eg. no change mesh res, remeshing
- Therfore, the surface topology
  - E.g. no breaking apart, fusing parts
- The mesh attributes
  - Such as color, UV-map…
  - Exceptions: positions, normals
- The textures
  - Use a texture animation instead?

49

## Blend shapes: authoring

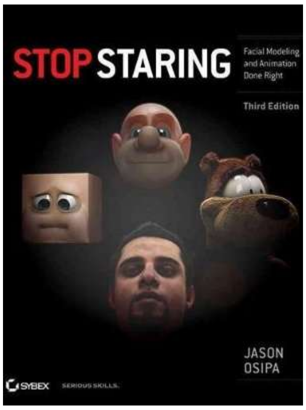


1. Editing base shape
   - including: uv-mapping, texturing, etc.
2. Re-edit it for each shape-key! …while preserving: connectivity, textures, etc:
   - with low poly editing
   - or with subdivision surfaces…
   - or with parametric surfaces…
   - or with scupting.

50

## Blend shapes: authoring

- Handbook for blend-shape based face animation:
  - "Stop Staring" (3d edition) Jason Osipa
  - Covers: style, expression…
  - Non technical (high level)
  - Not about specific tools e.g. Blender, Maya




51

## Blend shapes: pros and cons

- During authoring:
  - 👍 flexible, expressive, huge number of DOF… (too many?)
  - 👎 work intensive to construct
  - 👎 expensive to store

but, not as bad as old sprites,

because
(1) shared of connectivity, textures, attributes
(2) keyframes / inbetweens!

- During use (by animator)
  - 👍 easy to use (just define global weights)
  - 👎 RAM cost
  - 👎 very little degree of freedoms (too few?)

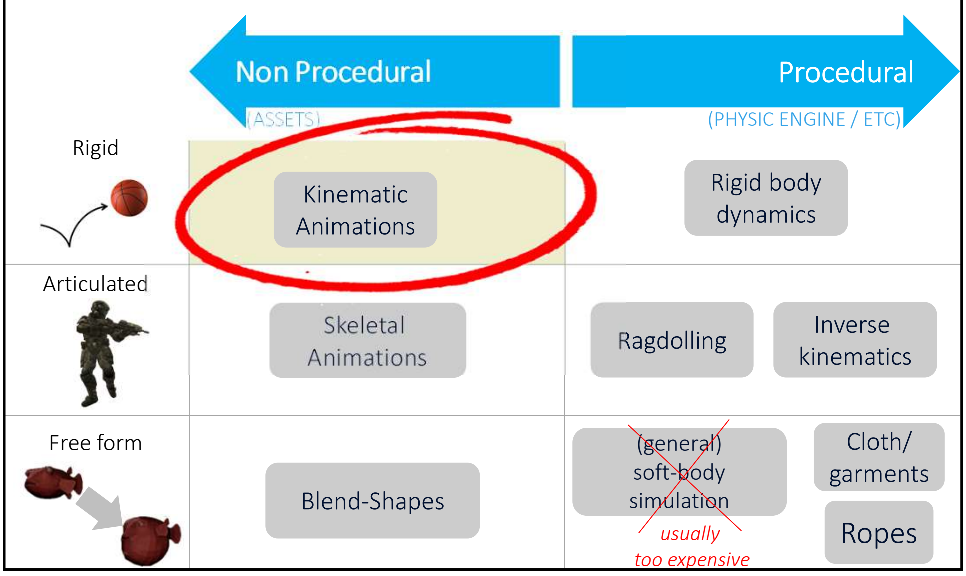
53

# Blend shapes: open challenges

- Capturing:
  - from a stream of meshes
  - e.g. : from a RGBD camera (like Microsoft Kinect) to a blend-shape: difficult!
- Compression
  - e.g.: reduce number of keyframes
- Streaming
  - server sends animation to client while it runs
- LOD-ding
  - like for meshes (but more difficult)

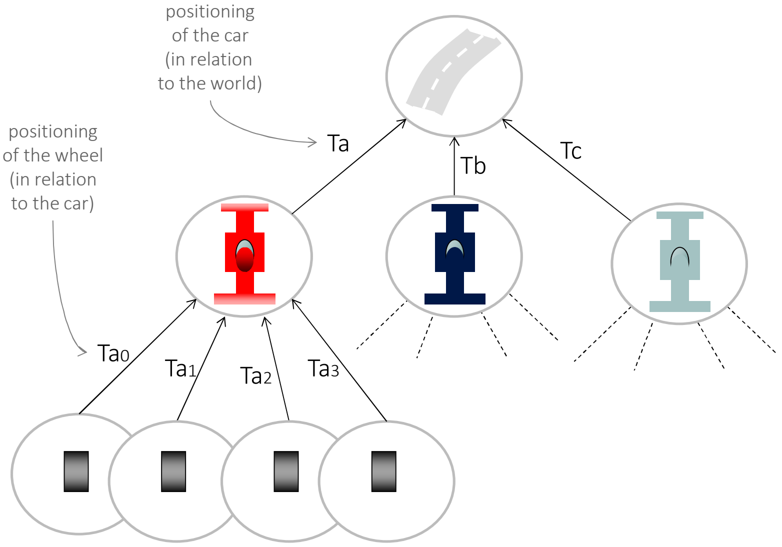
54

# Animations in games



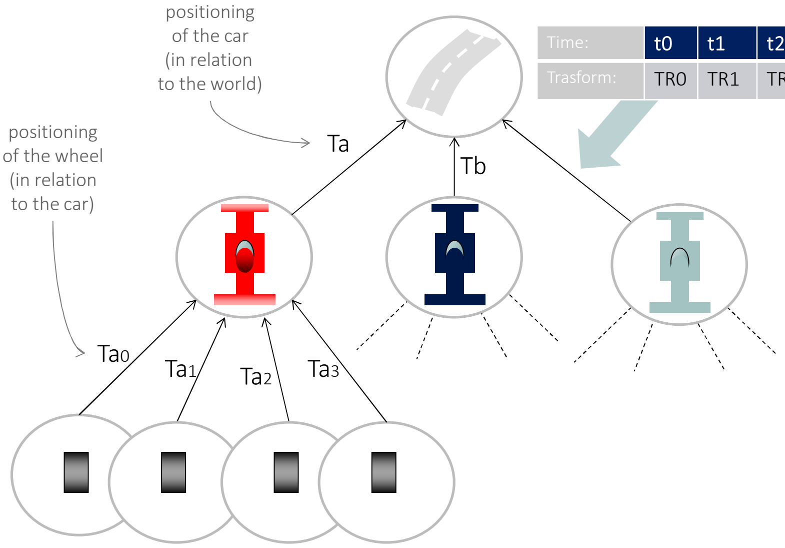

55

## Scene graph




56

## Animated Scene graph…
## (“kinematic” animations)

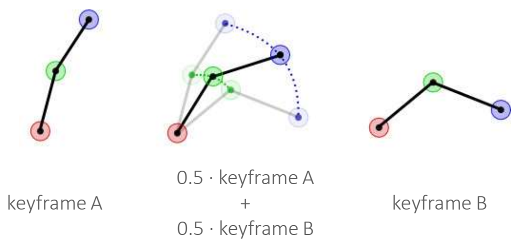



| Time: | t0 | t1 | t2 | t3 | t4 |
|---|---|---|---|---|---|
| Trasform: | TR0 | TR1 | TR2 | TR3 | TR4 |

57

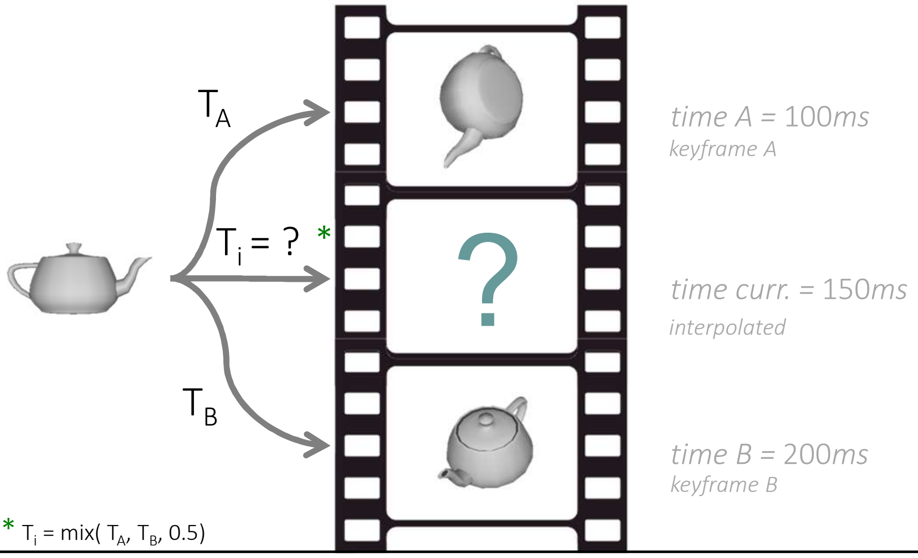
# Interpolating keyframes
(applies to *all kinds* of asset animations)

- Keyframes
  +
  in-betweens (interpolation)




59

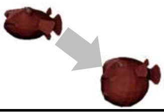
# Keyframe interpolation
(for kinematic animations)




* $T_i$ = mix( $T_A$, $T_B$, 0.5)

60

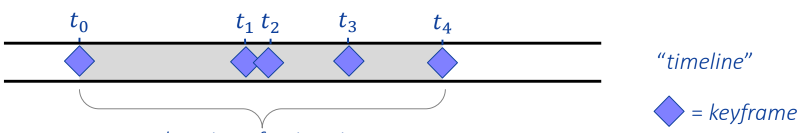
# Keyframes and inbetweening

| | Non Procedural (ASSETS) | Procedural (PHYSIC ENGINE / ETC) |
|---|---|---|
| Rigid  | stored Keyframes + generated in-betweens | Rigid body dynamics |
| Articulated  | stored Keyframes + generated in-betweens | Ragdolling; Inverse kinematics |
| Free form  | stored Keyframes + generated in-betweens | ~~(general) soft body simulation~~ *usually too expensive*; Cloth/ garments; Ropes |

61

# Keyframes and in-betweens
## (applies to *all kinds* of asset animations)

- The animation asset stores only a subset of frames ("key"-frames)
  - each with its own associated *time*




- Other frames ("inbetweens") are interpolated keyframes
  - saves storage RAM
  - saves artist work (only keyframes are constructed)
  - animation can very smooth (avoids temporal aliasing) e.g. even when played at extreme slow-motion
  - requires ability to interpolate (key) frames!

62

# Keyframes and in-betweens
(applies to *all kinds* of asset animations)

the "temporal resolution" of the animation

- keyframes distribution can be *adaptive*
  - more keyframes only where needed
- inbetweening happens on demand
  - e.g., at each refresh of video
- keyframe *times* can be at arbitrary
  - not necessarily exact frames, not necessarily integers
  - all frames shown on screen will be in-betweens
- the better the interpolation schema
  → better in-betweens → fewer keyframes are needed
- editing the animation: asset
  - editing individual keyframes
  - editing keyframe *times* (e.g., to achieve non-linearity of moment, vary speed)
  - 1. pick a new time $t_i$ (not a keyframe)
    2. bake the in-between at $t$ as a new keyframe
    3. edit it!

63

# Kinematic animations

for certain nodes
in the scenegraph

- Just compute new transformations per frame
  - Often, just the rotation component
    (translation is constant)
- Or store transformations per keyframe
  - Then, interpolate them for any other frame
    *between* keyframes
- By cumulating the transformations in the graph, we can compute the final position of every node
  - This is called solving a "forward kinematic" problem
  - The inverse problem (from final position of certain nodes, compute the transform, especially the rotation) is called "inverse kinematic" (IK)

64