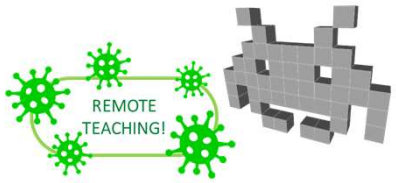
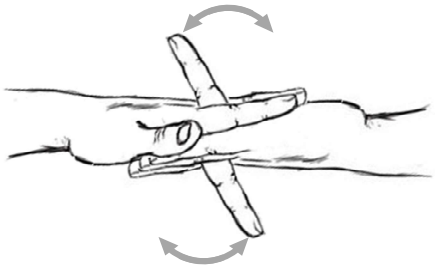
3D VideoGames
Unimi

Animations in games



Marco Tarini



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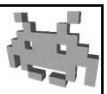
Course Plan



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 **3D Audio**
lec. 10: **Networking** for 3D Games
lec. 11: **Artificial Intelligence** for 3D Games
lec. 12: Game **3D Rendering Techniques**

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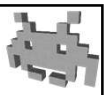
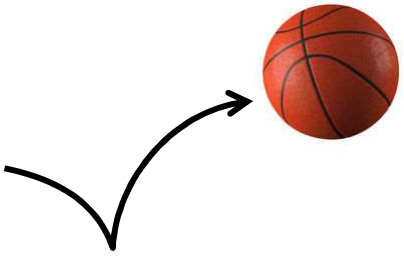
Types of animations in games



1. of rigid objects
   - animate scene transformations



(6 DoF per object)

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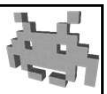
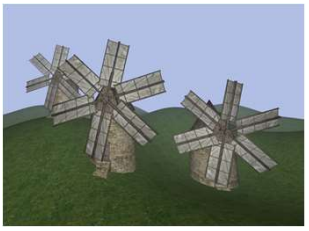
Types of animations in games



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



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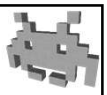
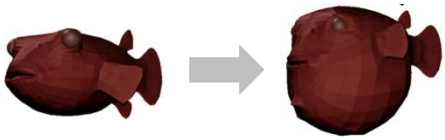
Types of animations in games



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



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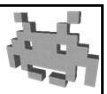
Types of animations in games



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

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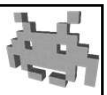
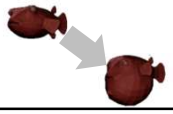
Types of animation and DoF (per keyframe)



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)

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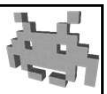
Animations in games



Authored	Procedural
• Assets!	• Physic engine
• Control: easy. full control by artists (e.g. for dramatic fx)	• 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)

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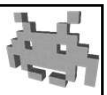
A digression on terminology



- depending on the context,
  the opposite of "procedural", can be…
  - baked :
    'pre-cooked', 'frozen' into an asset,
    (when something was produced procedurally)
  - asset :
    stored as an asset (irrespective of origin),
    that is, read from the disk (or streamed from web)
  - scripted :
    stored as a (*simple!*) script
    but, the procedure to create something can well be a script!
    e.g. "this *script procedurally generates* a level"
  - authored / manually designed / edited :
    made by a digital artist (as opposed to, by a program)
  - (fully) simulated :
    the output of a (*complex!*) simulation

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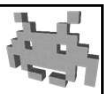
Summary: Types of authored animations



- of objects made of rigid subparts
  - including joints: robots, cars…
  - → "forward kinematics animations"
    (dynamic changes of modelling transform)
- of deformable articulated objects
  - with some internal skeleton
  - e.g: most virtual characters:
    humans / animals / monsters / anything in between
  - → "skinning" / "rigging"
- of generic deformable objects
  - e.g. faces, an umbrella, stuff with membrane…
  - "per-vertex animations" / "blend shapes" / "morph targets"

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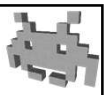
Animations in games: authored or procedural?



- Or… a mix
  - Example 1: *primary* animations: authored
    secondary animations: physically generated
  - Example 2: *alive* characters: scripted
    dead characters: physically generated (ragdolls)
  - Example 3: walk cycle: authored (skeletal animation)
    feet placement: procedural (inverse kinematic)
  - Example 4: normal "behavior", e.g. sparring: authored
    gaze control: scripted
  - Example 5: normal "behaviors" e.g. jumping, running
    modifications / transitions: AI generated
  - *and more*
- mixing AI with authored animations is a frontier in CG and Interactive techniques!

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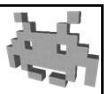
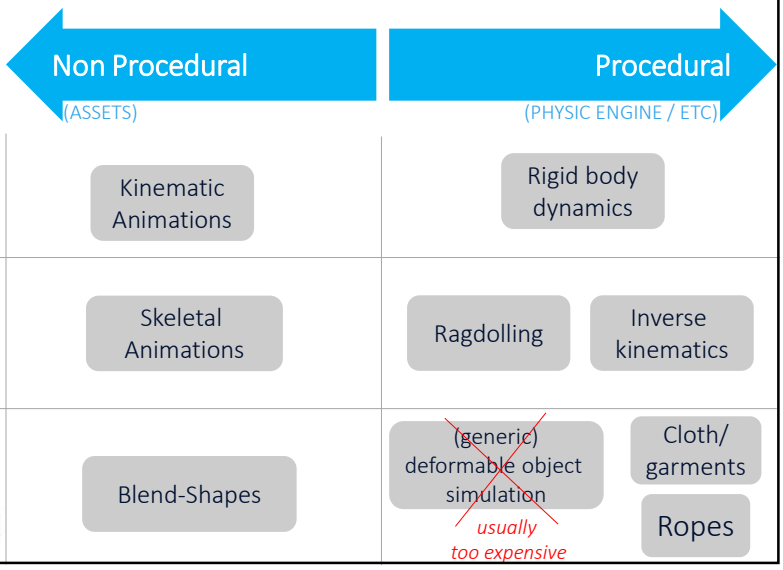
Animations in games





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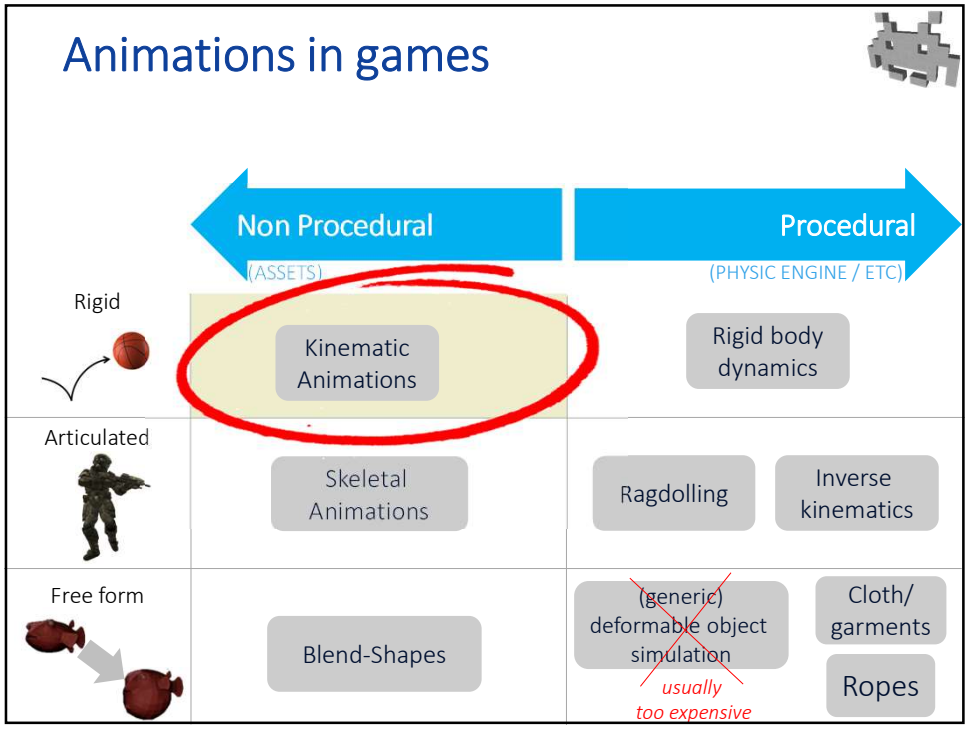
Animations in games
Non Procedural
(ASSETS)
Procedural
(PHYSIC ENGINE / ETC)
Rigid
Articulated
Free form
Kinematic Animations
Rigid body dynamics
Skeletal Animations
Ragdolling
Inverse kinematics
Blend-Shapes
(generic) deformable object simulation
usually too expensive
Cloth/ garments
Ropes

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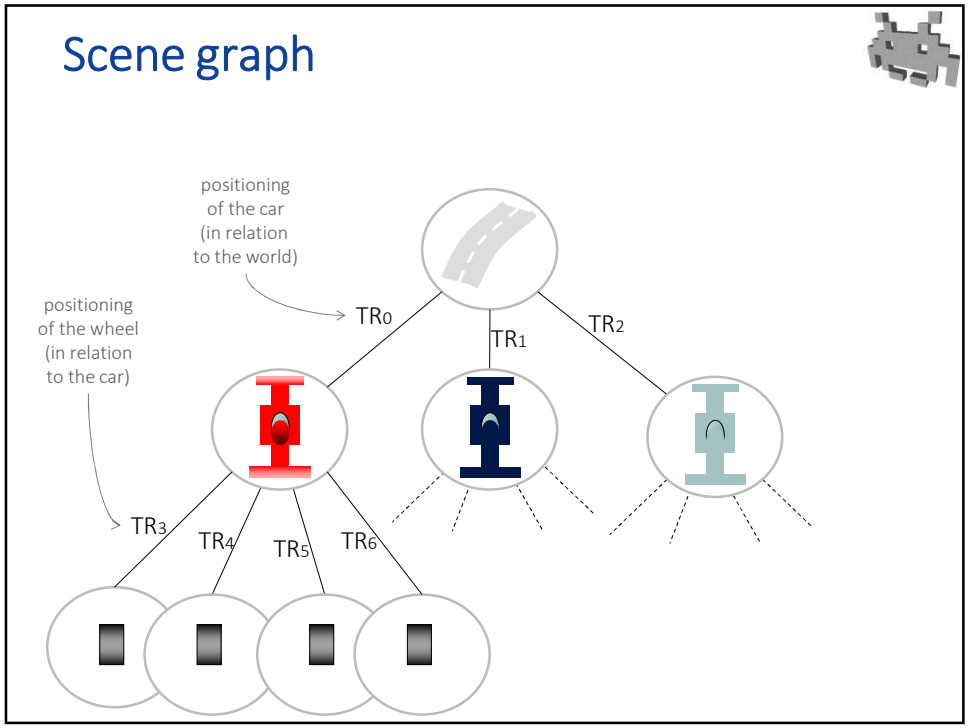
Scene graph
positioning of the car (in relation to the world)
positioning of the wheel (in relation to the car)
TR0
TR1
TR2
TR3
TR4
TR5
TR6

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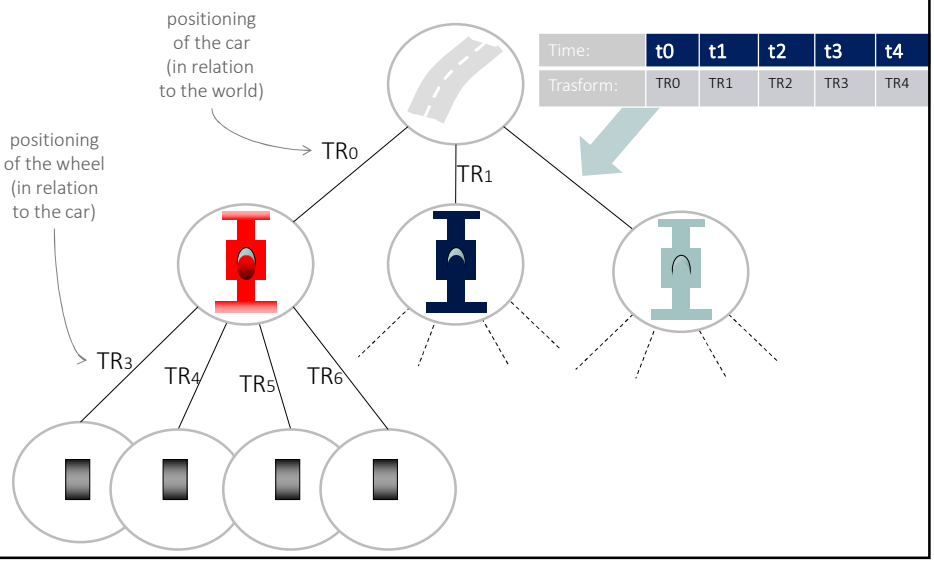
Animated Scene graph… (“kinematic” animations)



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Kinematic animations: how?

- way 1:
  - just scripting
- way 2:
  - editing in a animation software
    - cinema 4D, blender, 3D max, …
    - (including use of I.K. as part of the interface)
  - export animation
    - as a sequence of keyframes
    - File formats: collada, fbx, …

asset: the script

Time:	t0	t1	t2	t3	t4
A==>B:	TR0	TR1	TR2	TR3	TR4
B==>C:	TR0	TR1	TR2	TR3	TR4

asset: the animation

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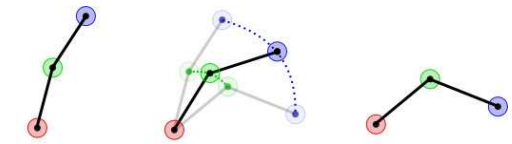
Interpolating keyframes
(applies to *all kinds* of asset animations)

- Keyframes
  +
  in-betweens (interpolation)



keyframe A | 0.5 · keyframe A + 0.5 · keyframe B | keyframe B

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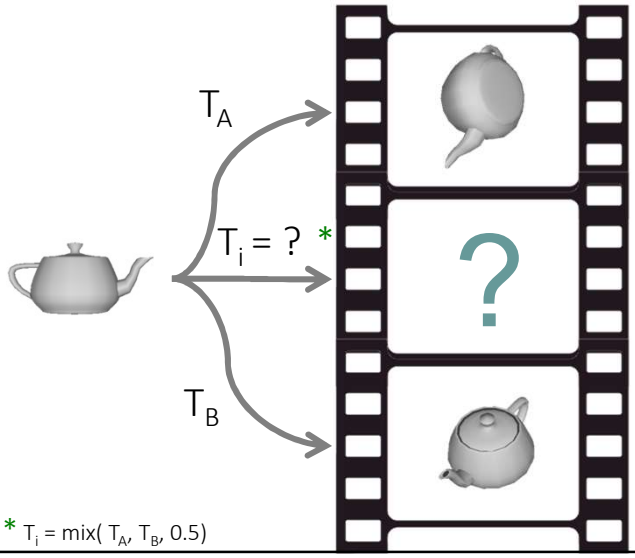
Keyframe interpolation
(for kinematic animations)



time A = 100
keyframe A

time curr. = 150
interpolated

time B = 200
keyframe B

* T_i = mix(T_A, T_B, 0.5)

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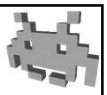
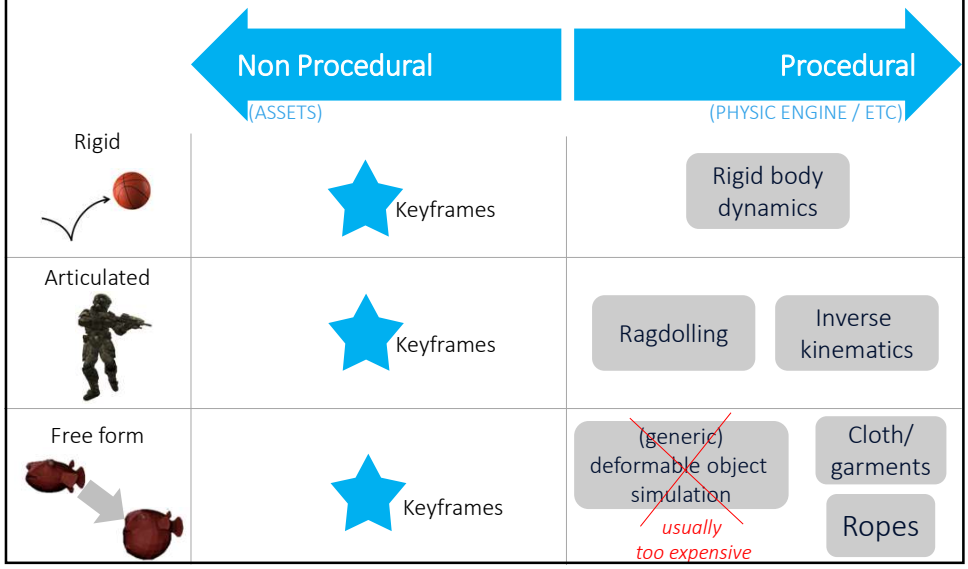
Keyframes and inbetweening





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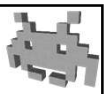
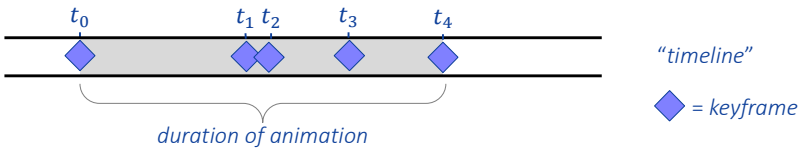
Keyframes and in-betweens
(applies to *all kinds* of asset animations)



- 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!

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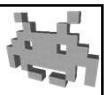
Keyframes and in-betweens
(applies to *all kinds* of asset animations)



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 rate of videoframe
- keyframe *times* can be at arbitrary
  - not necessarily exact frames, not necessarily integers
  - all frames shown on screen will be inbetweens
- the better the interpolation schema
  → better in-betweens → fewer keyframes are needed
- editing the animation:
  - editing individual keyframes
  - editing keyframe *times* (e.g. achieves non-linearity of speed)
  - pick a new time t_i (not a keyframe)
    bake the inbetween at *t* as a new keyframe
    edit it!

asset

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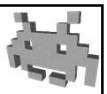
Kinematic animations



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)

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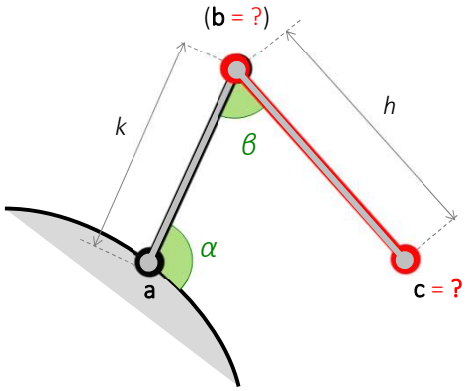
"Forward Kinematic"



find **c** (and **b**), given **a**, α, β, k, h

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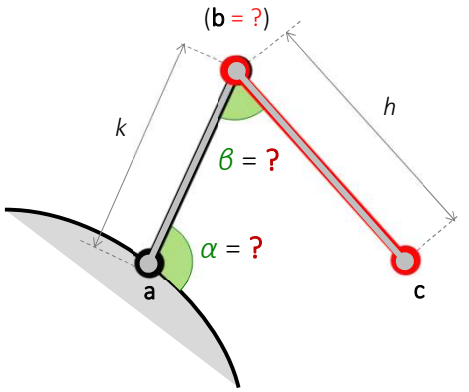
Inverse Kinematic (IK)



find α, β (and **b**), given **a**, **c**, k, h

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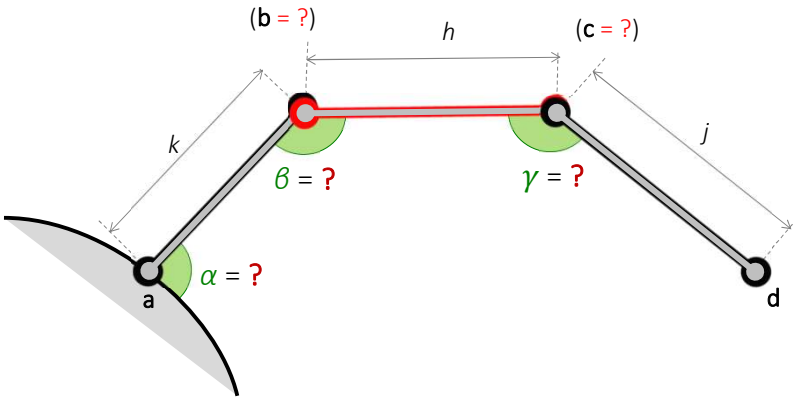
Inverse Kinematic (IK):
for any number of joints



solve for α , β , γ (and **b**, **c**), given **a**, **d**, k, h, j

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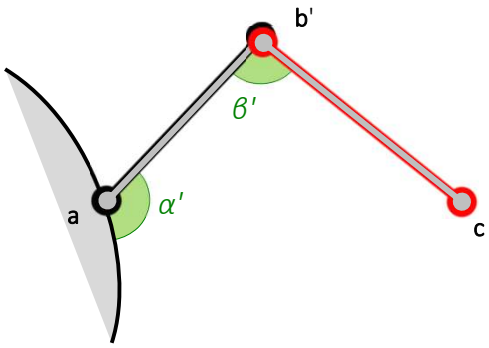
Inverse Kinematic (IK):
an ambiguity



solve for α, β (and **b**), given **a**, **c**, k, h

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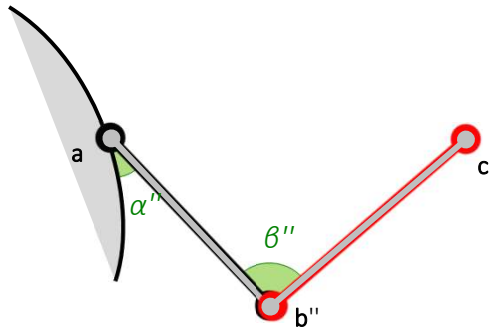
Inverse Kinematic (IK): an ambiguity



solve for α, β (and **b**), given **a**, **c**, *k*, *h*

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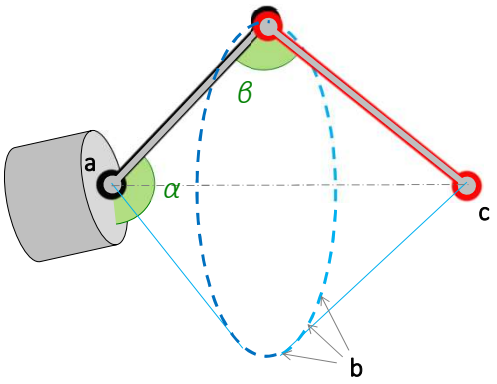
Inverse Kinematic (IK) in 3D: more ambiguities



solve for α, β (and **b**), given **a**, **c**, *k*, *h*

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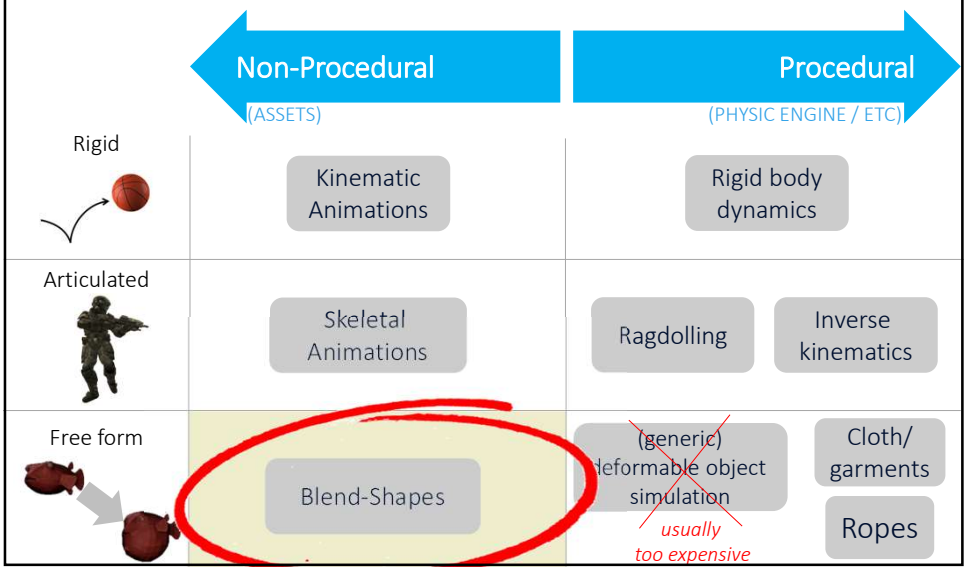
Animations in games
(of 3D Solid Objects)



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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)

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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?

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Reminder: representation of a mesh

- Indexed mode :
  - Geometry: array of vertex positions
  - Attributes:
    - stored at vertices
  - Connectivity:
    - Array of triangles (or polygons)
    - Each triangle = a triplet of indexes to vertice

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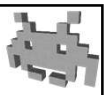
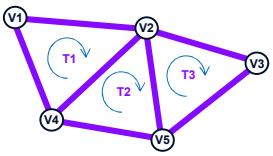
Mesh (data structure)





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)

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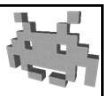
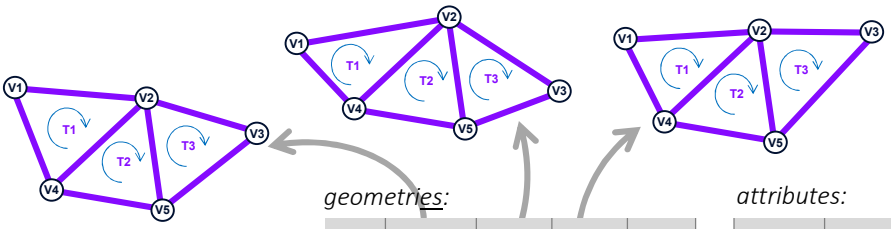
Blend shapes (data structure)





connectivity (indexed)

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

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)

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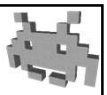
Blend shapes



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

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

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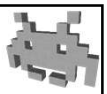
Blend shapes
(as a data structure, e.g. C++)



- 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 */
};
```

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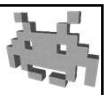
Blend shapes
(as a data structure, e.g. C++)



- 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 */
};
```

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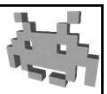
Blend-shapes:
most common file formats



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

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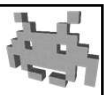
Blending shapes of a blend-shape



- Blending between two $shape_A$ and $shape_B$:
  - with relative BlendShapes:
    $shape_{base} + w_A \cdot delta\_shape_A + w_B \cdot delta\_shape_B \cdot w_B$
    - with w_A , w_B usually between 0 and 1
    - otherwise, it's an "exaggeration"
  - with absolute BlendShapes : (equivalently) (verify!)
    $(1- w_A - w_B) \cdot shape_{base} + w_A \cdot delta\_shape_A + w_B \cdot delta\_shape_B$
    - Note: it's an extrapolation if $0 \leq w_A , w_B , w_A + w_B \leq 1$
    - Otherwise, it-s an extrapolation
- It's trivial to extend to a blend of multiple shapes

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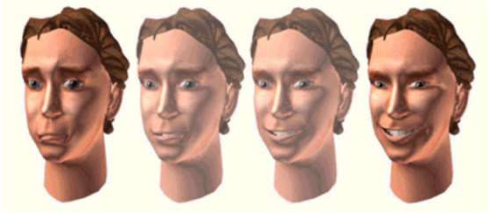
Uses of Blend-Shapes: facial expressions



shape A shape B

here: shapes = facial expressions
(typical use; that's why they are also called "face morphs"

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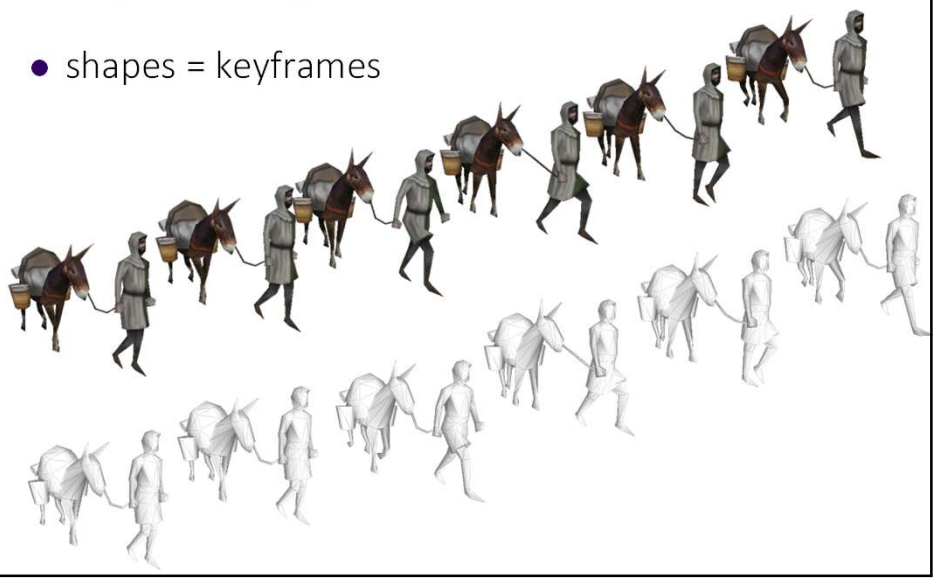
Uses of Blend shapes: temporal sequences

- shapes = keyframes



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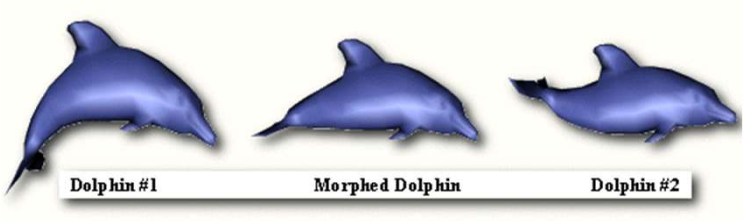
Uses of Blend shapes: temporal sequences

- Temporal sequences
  - shapes = keyframes



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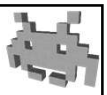
Blending keyframes of a temporal sequence



- 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 $t_B < t < t_C$
- *then…*
  - which shapes to blend? shape_B , shape_C
  - weights? $w_B = \frac{t - t_C}{t_B - t_C}$ $w_C = (1 - w_B) = \frac{t - t_B}{t_C - t_B}$

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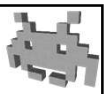
Blending keyframes of a temporal sequence with transition functions



- 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 $t_B < t < t_C$
- *then…* *transition function*
  - which shapes to blend? shape_B , shape_C
  - weights? $w_B = f\left(\frac{t - t_C}{t_B - t_C}\right)$ $w_C = (1 - w_B)$

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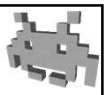
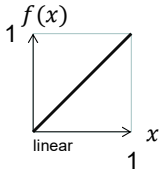
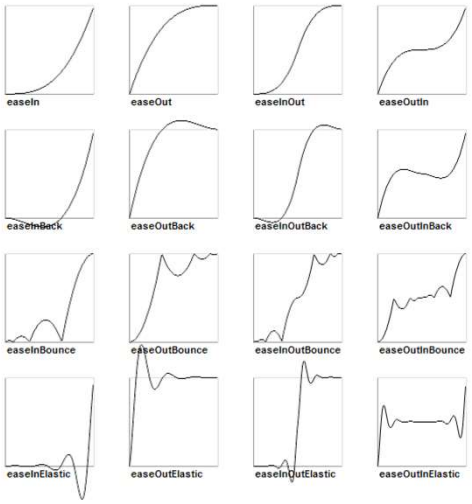
Transition functions
(applies to all animation types with keyframes)



- Not necessarily the Linear one



$f(x) = x$



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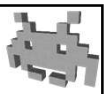
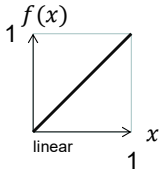
Transition functions
(applies to all animation types with keyframes)

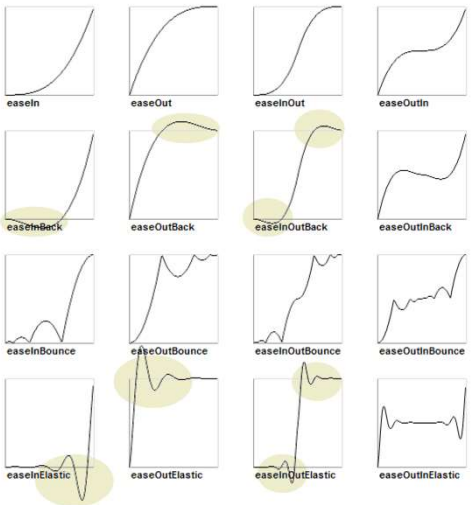


- Not necessarily the Linear one



$f(x) = x$

NB: = extrapolation !
i.e. exaggeration



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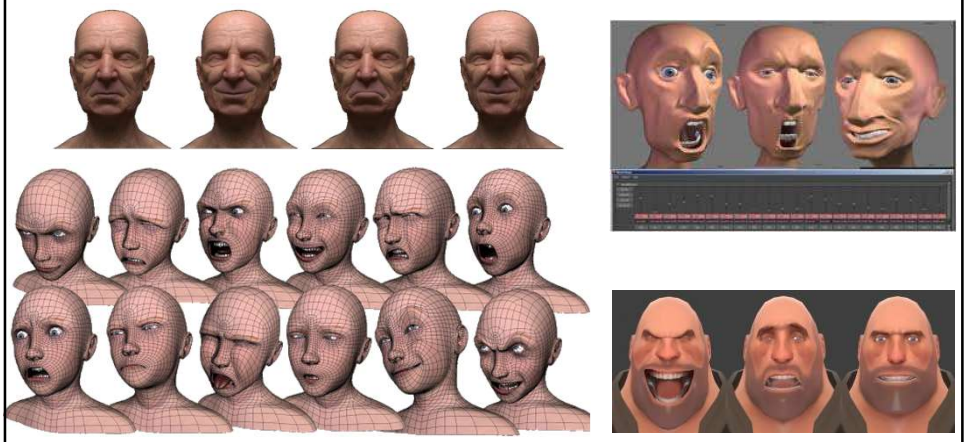
Uses of Blend shapes: facial animations



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

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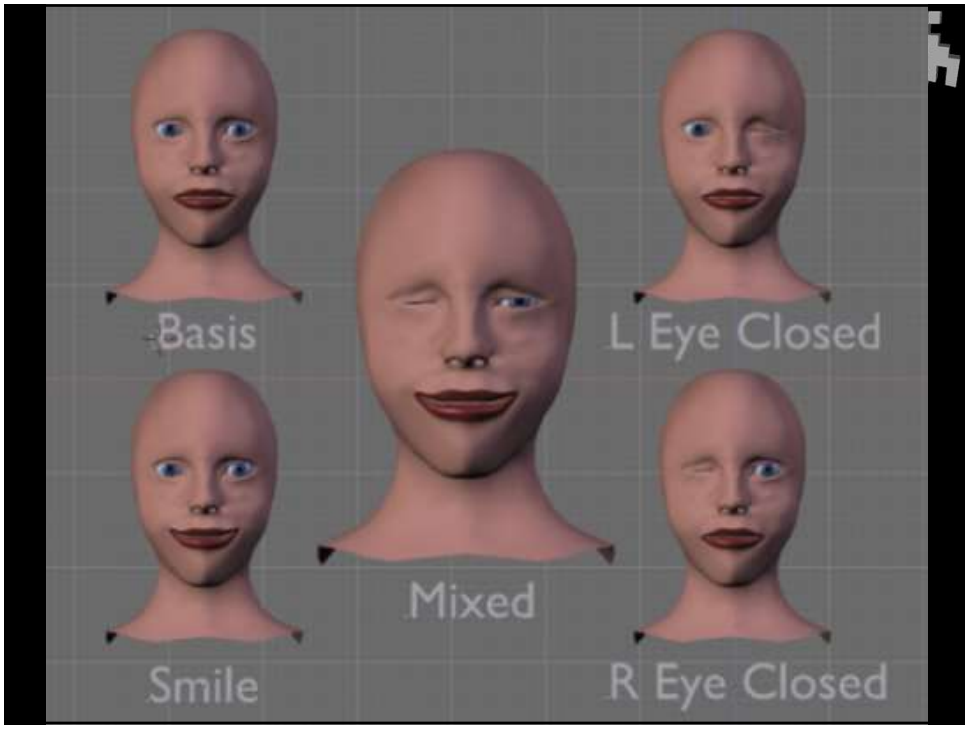

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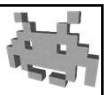
Using facial animations as Blend shapes



- 3D Modeller authors:
  the set of blend-shapes
- Animator (of expressions) picks:
  weights
  - eg.: with sliders
  - assisted / substituted by automatisms
    - lip sync
    - dynamically determined expressions
- Keyshape Blending: by rendering engine

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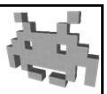
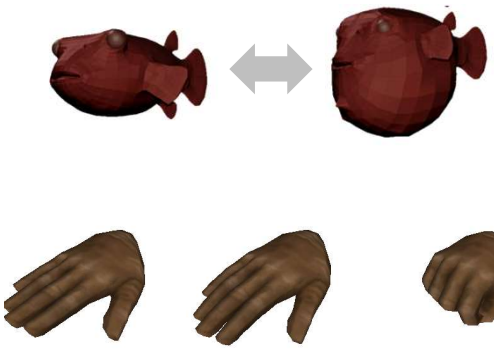
Uses of Blend-Shapes: generic deformations



- Baked poses



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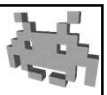
Uses of Blend-Shapes: variants of one given object



- mixable!

masculine outfit

feminine outfit

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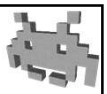
Uses of Blend-Shapes variants of one given object



- mixable!

human

orc

goblin

dwarf

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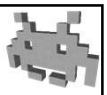
Uses of Blend-Shapes



- 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

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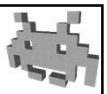
Uses of Blend shapes



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

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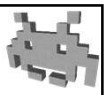
What a blend shape *cannot* do



- Change connectivity
  - eg. change mesh res, remeshing
- Change topology
  - breaking apart, fusing parts
- Change most attributes
  - eg color, UV-map…
- Change textures
  - Use a texture animation instead?

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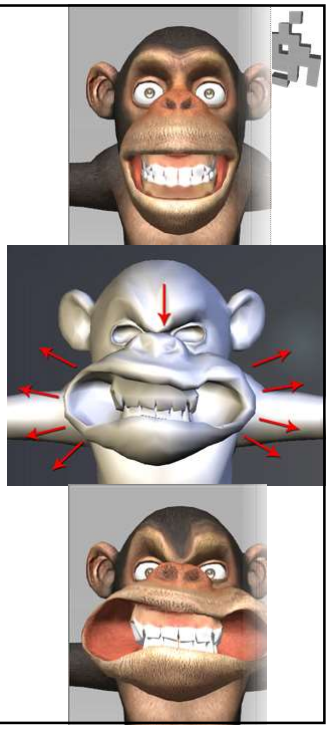
Blend shapes: authoring



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.

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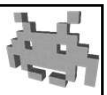
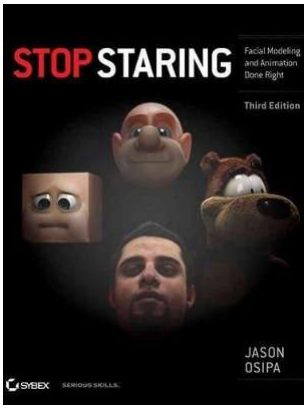
Blend shapes: authoring



- 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



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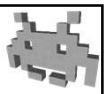
Blend shapes: hot to obtain them



- Capture:
  - 3D acquisition of base shape B0
    - (including: simplification, remeshing, uv-mapping, etc)
  - capture subsequent shapes B1, B2…
    - e.g. real-time (kinect), o 3D scanning for each shape
  - compute a morph B0 => B1
    - "non rigid mesh alignment"

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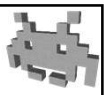
Blend shapes: pros and cons



- During authoring:
  - 👍 flexible, expressive, huge number of DOF… (too many?)
  - 👎 work intensive to construct
  - 👎 expensive to store
- During use (by animator)
  - 👍 easy to use (just define global weights)
  - 👎 RAM cost
  - 👎 very little degree of freedoms (too few?)

but, not as bad as old sprites,

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

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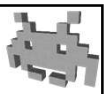
Blend shapes: open challenges



- 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)

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