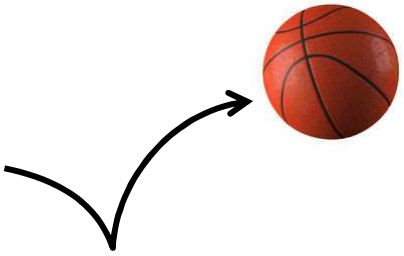
Types of animations in games

1. of rigid objects
   - animate modelling transformations



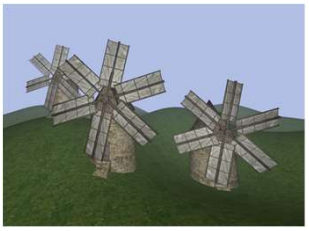
(6 DoF per object)

3

Types of animations in games

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

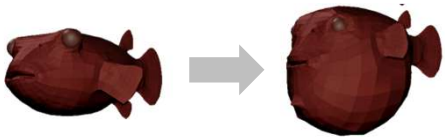




4

Types of animations in games

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



5

Types of animations in games

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

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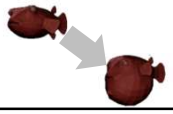
Types of animation and DoF (per keyframe)

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

Non procedural	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 / contexts
(consumes RAM)	(consumes GPU)

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Animations in games

- Or… a mix
  - ex1: *primary* animations: scripted
    secondary animations: computed
  - ex2: *alive* characters: scripted
    dead characters: computed (ragdolls)
  - *and more*

- a frontier in CG and Interactive techniques!

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Summary: Types of scripted 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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A digression on terminology

- The opposite of "**procedural**", depending on the context, can be…
  - **baked** : 'pre-cooked', 'frozen' into an asset, (when it 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")
  - **(manually) designed / edited** : made by an artist (as opposed to: by a program)
  - **(fully) simulated** : the output of a (complex!) simulation

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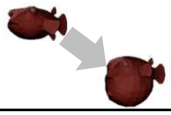
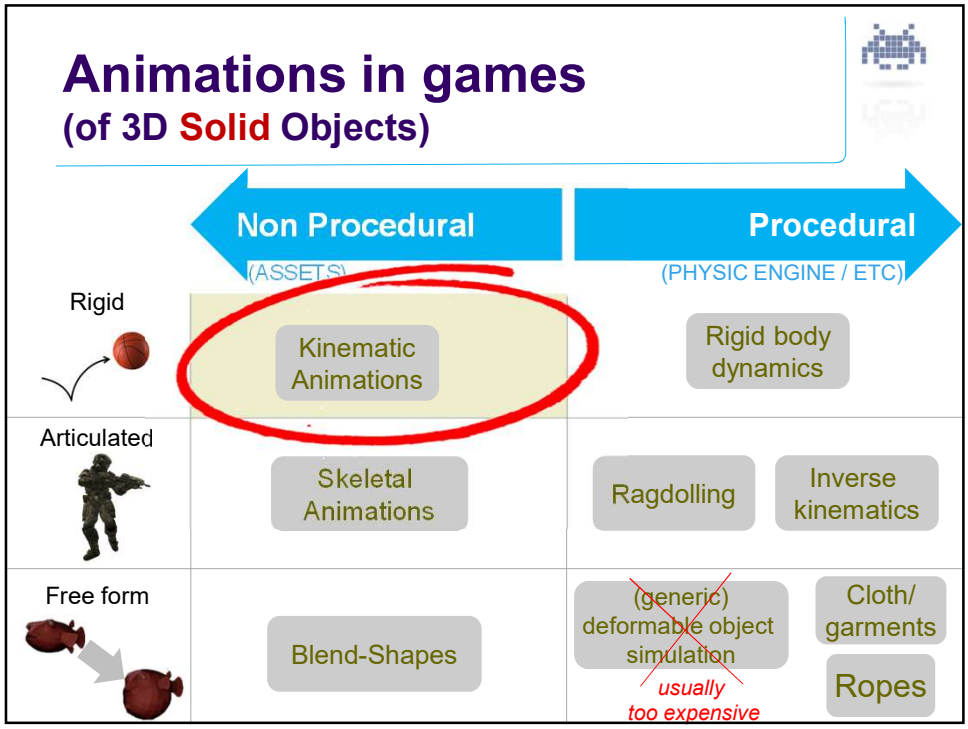
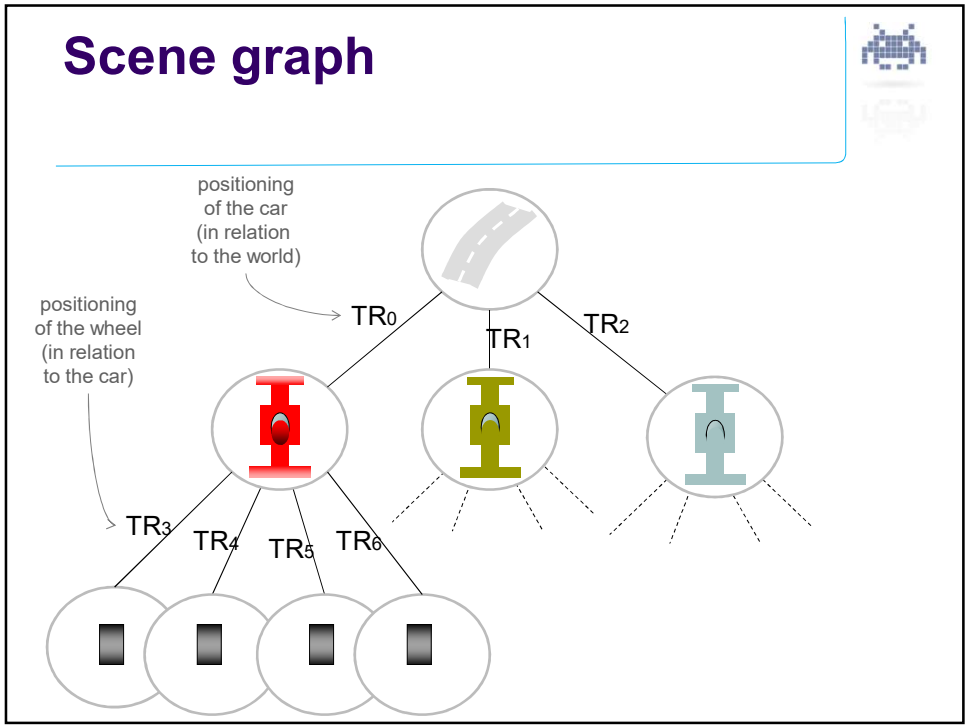
Animations in games
(of 3D Solid Objects)

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

12


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
(generic) deformable object simulation
usually too expensive
Cloth/ garments
Ropes

13


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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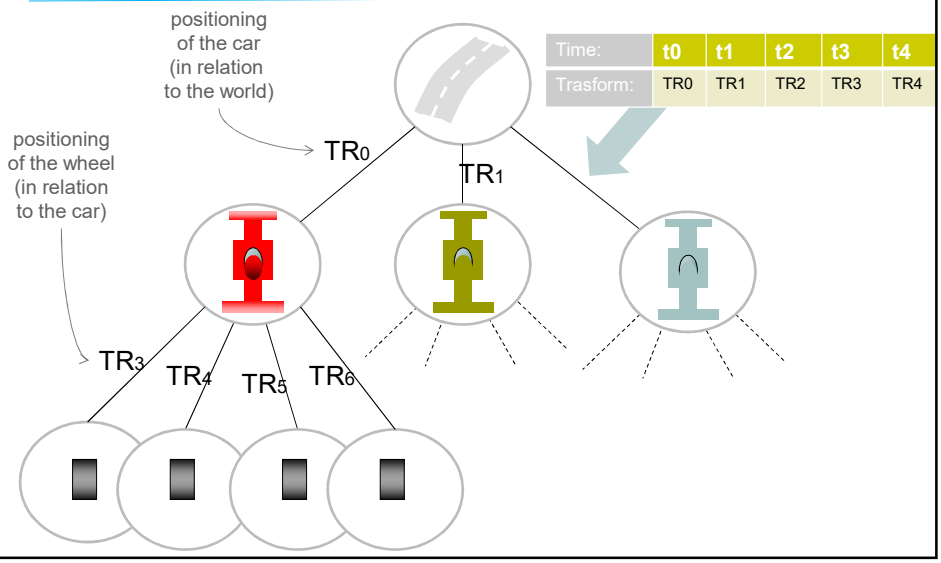
Animated Scene graph…
(“kinematic” animations)



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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

DEMO !

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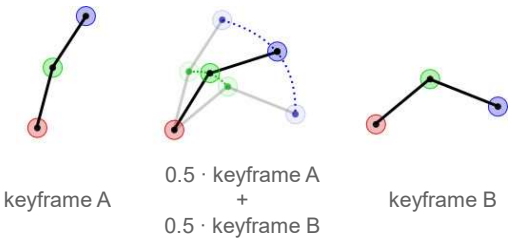
Interpolating keyframes
(applies to *all kinds* of animations)

- Keyframes
  +
  interpolation



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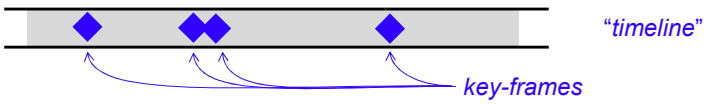
Interpolating keyframes
(applies to *all kinds* of animations)

- The animator authors:
  - a set of *keyframes*
  - each with an associated time



- Status of the ani at any other **frame**:
  interpolation between **keyframes**
  - saves artist work
  - saves storage

- note: keyframes distribution can be *adaptive*
  - concentrate keyframes where needed / not linear

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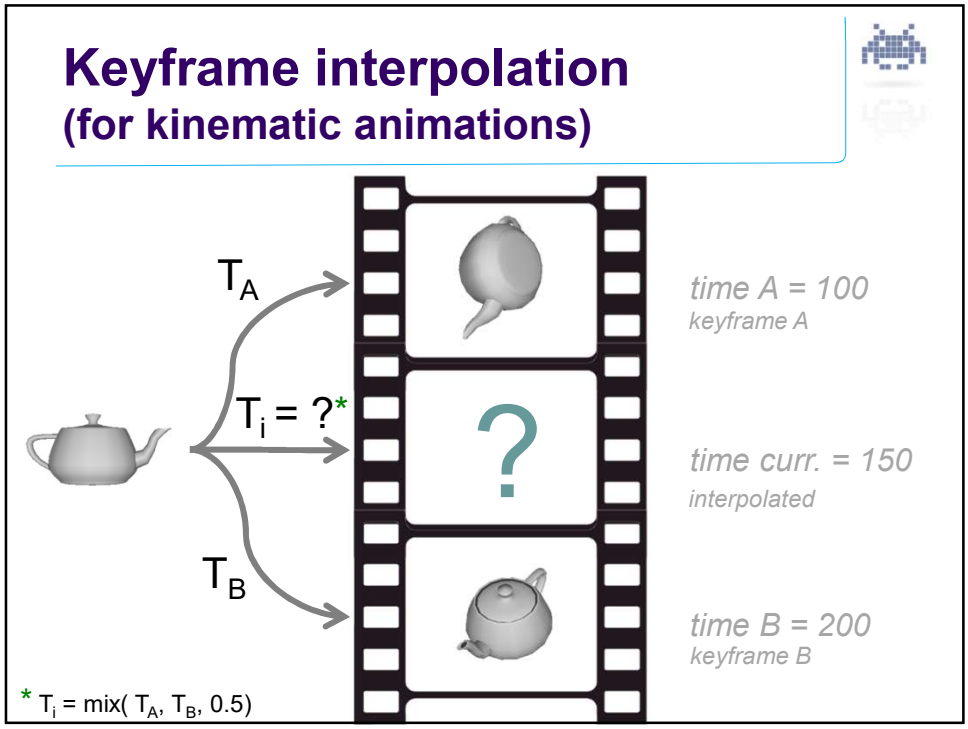
Keyframe interpolation
(for kinematic animations)
T_A
T_i = ?*
T_B
?
time A = 100
keyframe A
time curr. = 150
interpolated
time B = 200
keyframe B
* T_i = mix(T_A, T_B, 0.5)

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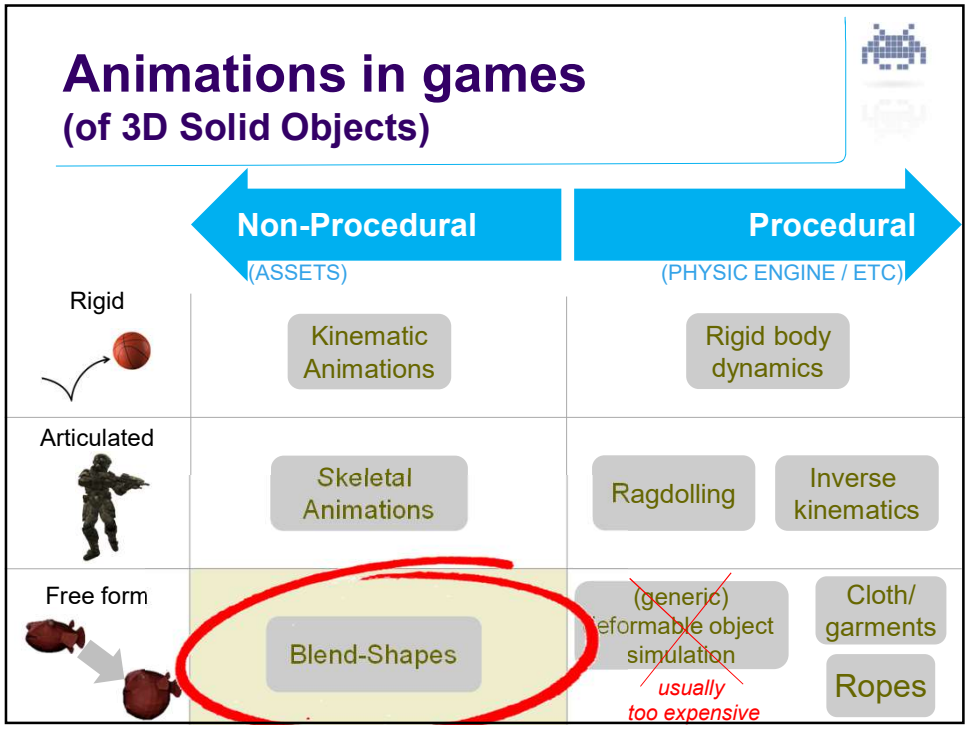
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Skeletal Animations
Ragdolling
Inverse kinematics
Free form
Blend-Shapes
(generic) deformable object simulation
usually too expensive
Cloth/ garments
Ropes

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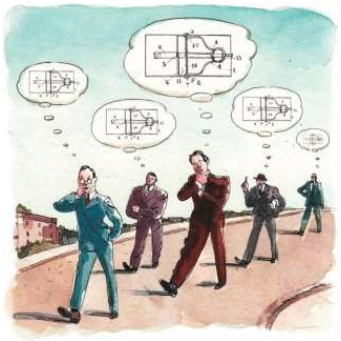
Asset for free-form animations: Blend shapes

- 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):
  a sequence of sprites
- Animation in 3D:
  a sequence of meshes?

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Reminder: representation of a mesh

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

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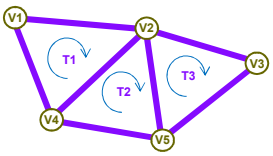
Blend shapes
(as a data structures)



*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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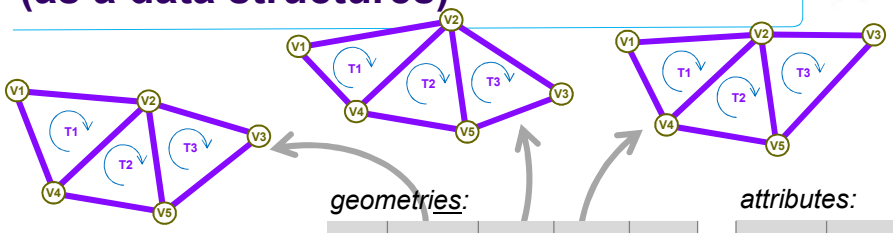
Blend shapes
(as a data structures)



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

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Blend shapes

- A mesh with several associated geometries
- I.e. a sequence of meshes ('shapes') with
  - shared connectivity
  - shared attributies
    - (except maybe normals / tangents)
  - different geometries
  - (and shared textures as well)

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

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

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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++)

- **Indexed** mesh :

```
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 a sequence of meshes (es **.OBJ**)
    - making sure connectivity is coherent! (vertex ordering = the same)
- Complex:
  - **.DAE** (Collada)
  - **.FBX** (Autodesk)

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Interpolation between shapes

- Interpolating just the geometry:
  - with assolute BlendShapes : $shape_A \cdot w_A + shape_B \cdot w_B$
  - with relative BlendShapes: $shape_{base} + delta\_shape_A \cdot w_A + delta\_shape_B \cdot w_B$
- with: $0 \le w_A \le 0$
  $0 \le w_B \le 1$
  $w_A + w_B = 1$

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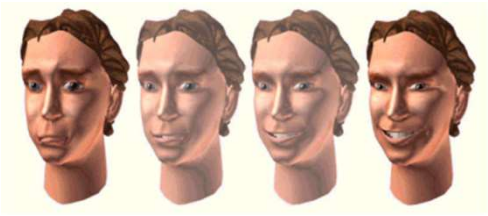
Uses of Blend-Shapes



shape A shape B

(shapes = facial expressions)

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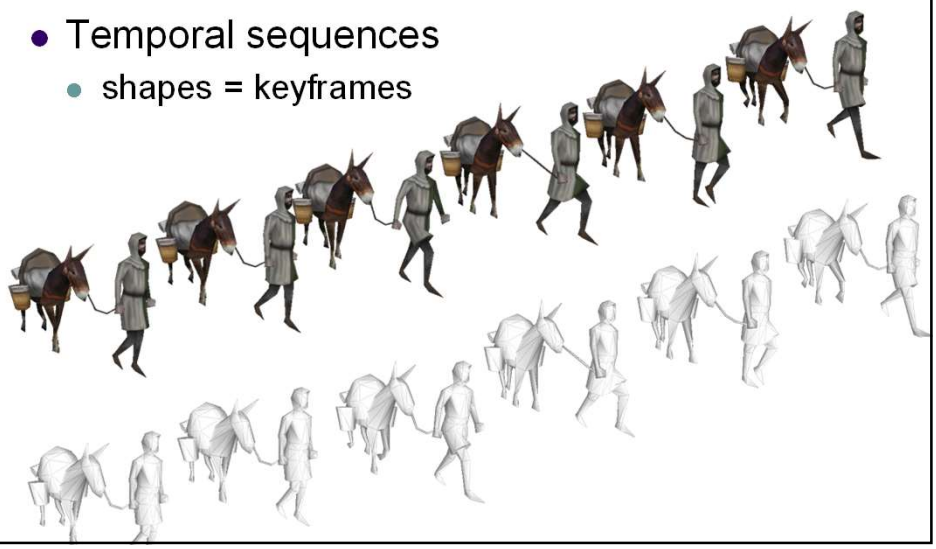
Uses of Blend shapes

- Temporal sequences
  - shapes = keyframes



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Use of Blend shapes

- Temporal sequences
  - shapes = keyframes

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Use of Blend shapes as temporal sequences

- 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
- current time: t with $t_B < t < t_C$
- interpolate betw. shapes: $shape_B$, $shape_C$
- 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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Use of Blend shapes as temporal sequences

- 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
- current time: t with $t_B < t < t_C$
- interpolate betw. shapes: $shape_B$, $shape_C$
- weights : $w_B = f\left(\frac{t-t_C}{t_B-t_C}\right)$ $w_C = f\left(\frac{t-t_B}{t_C-t_B}\right)$

transition function

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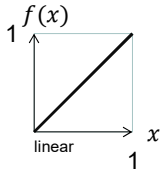
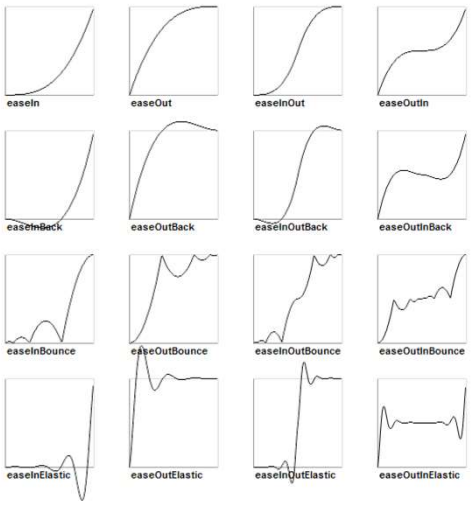
(general concept,
applies to all animation types)

Transition functions

- Not necessarily the Linear one



$f(x) = x$

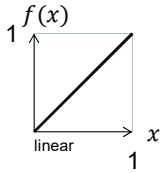


36

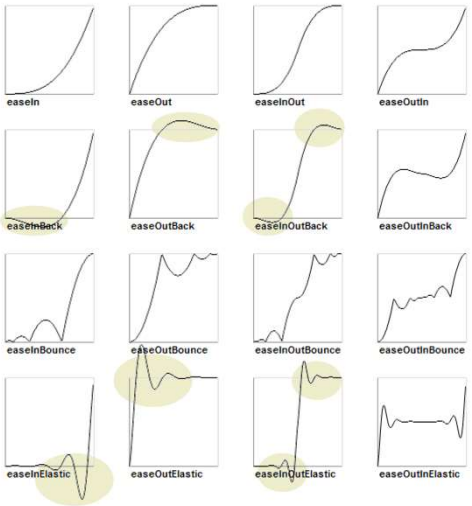
(general concept,
applies to all animation types)

Transition functions

- Not necessarily the Linear one



$f(x) = x$



NB: → extrapolation !
(→ exaggeration)

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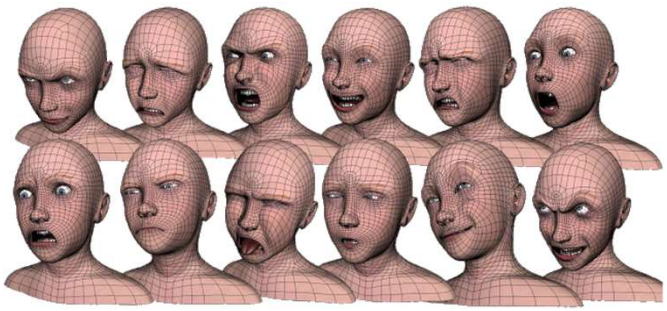
Uses of Blend shapes

- Facial animations
  - (one of the commonest uses)



Here together with skeletal animations (see later)
(mandible, neck, eyeballs)

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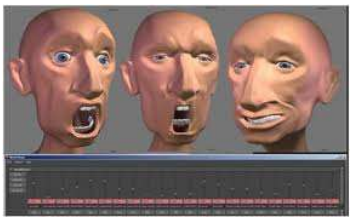
Usi delle Blend shapes

- Facial animations
  - (one of the commonest uses)



Here together with skeletal animations (see later)
(mandible, neck, eyeballs)

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Interpolation between more than two shapes

- Blending the shapes:
  - Absolute:
    $\text{shape}_A \cdot w_A + \text{shape}_B \cdot w_B + \text{shape}_C \cdot w_C + \ldots$

    with:
    $0 \le w_{A,B,C,\ldots} \le 1$

    or maybe not (extrapolation). Useful for…

    $w_A + w_B + w_C + \ldots = 1$

  - Relative:
    $\text{shape}_{base} + \text{shape}_A \cdot w_A + \text{shape}_B \cdot w_B + \text{shape}_C \cdot w_C + \ldots$

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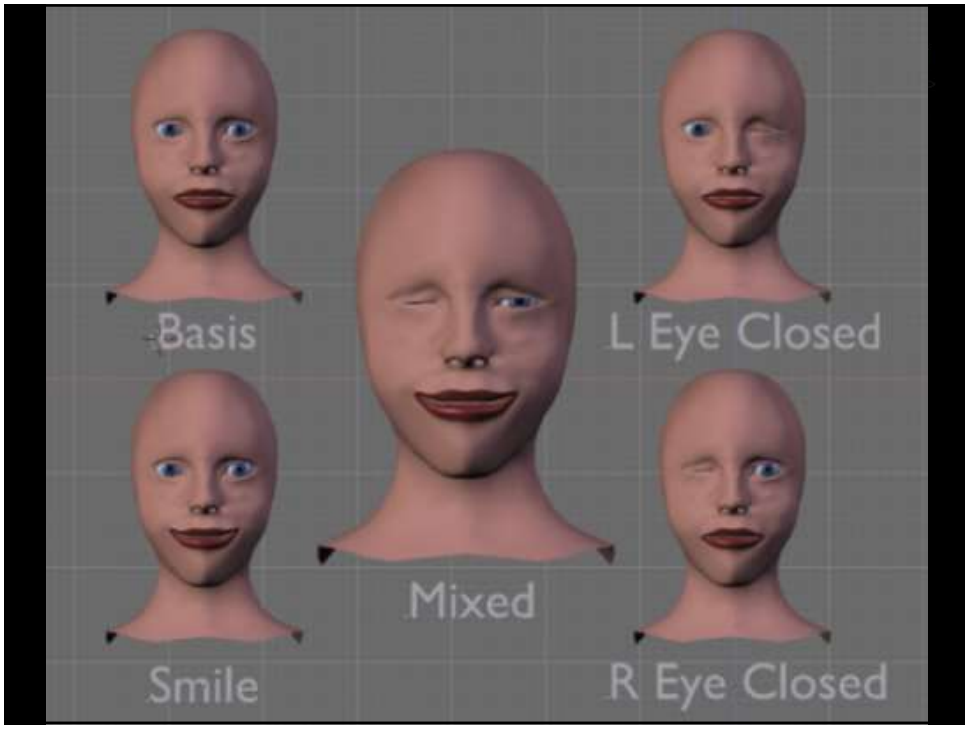

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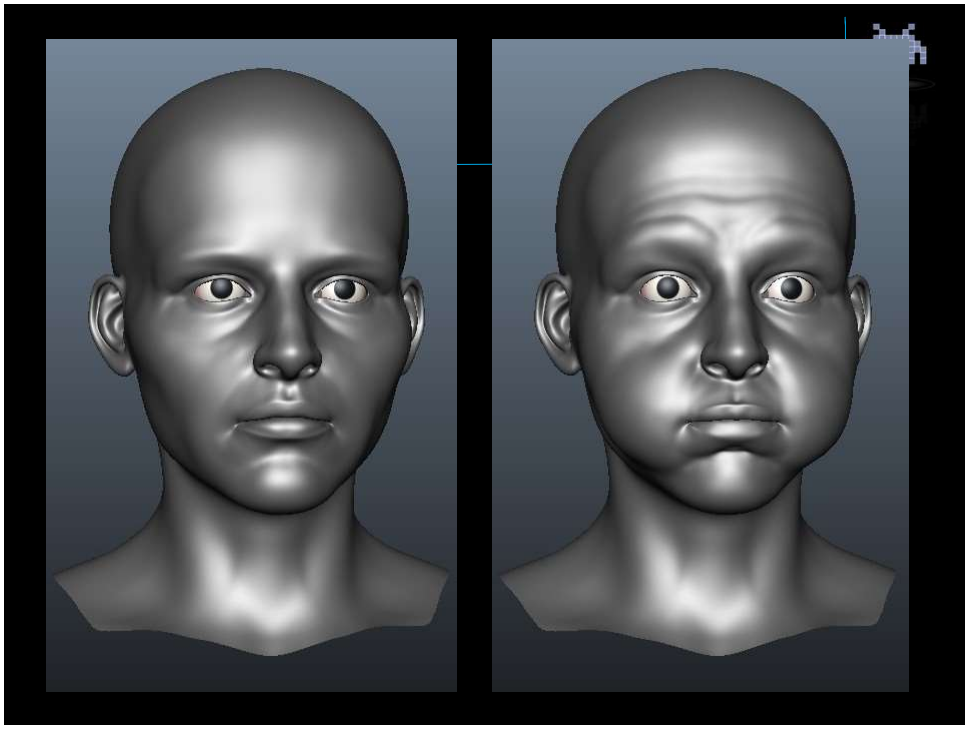

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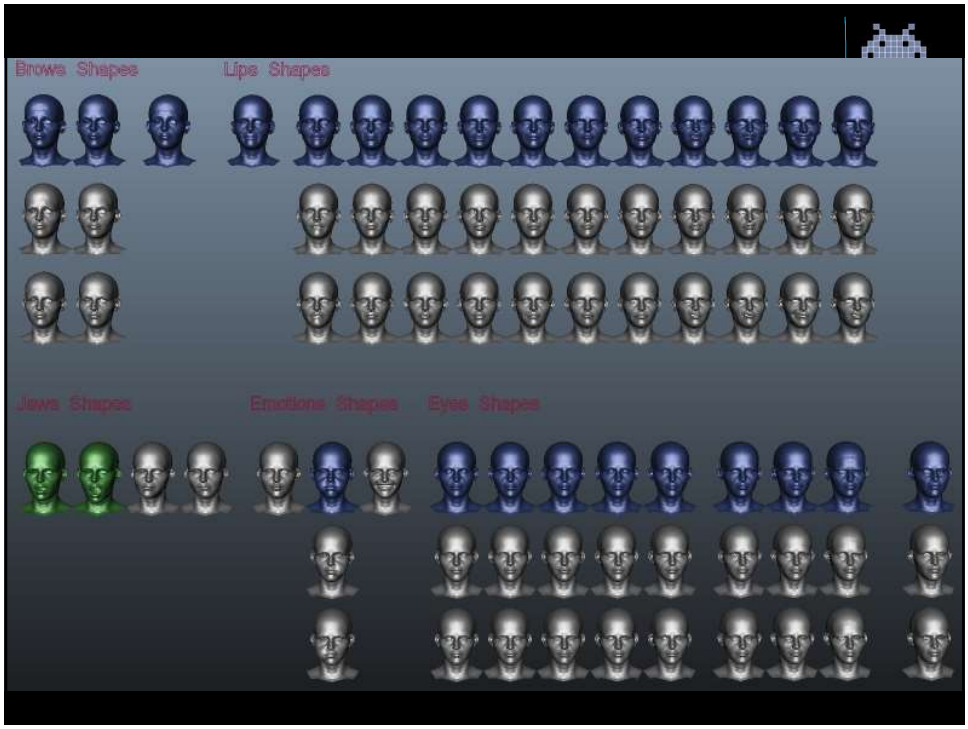

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Using facial animations as Blend shapes: pipeline

- 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

[VIDEO]

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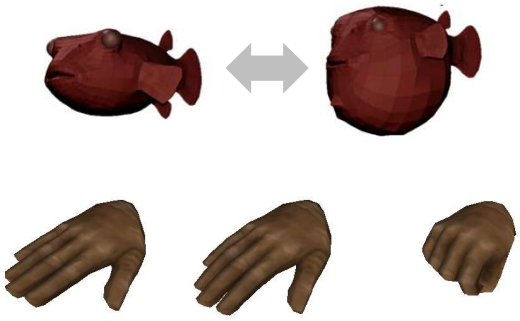
Uses of Blend-Shapes

- Set of useful/typical physical configurations
- Baked poses



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Uses of Blend-Shapes

- Variants of one give objects
  - (mixable!)

masculine outfit

feminine outfit

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Uses of Blend-Shapes

- Variants of one give objects
  - (mixable!)

huamn *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 an 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")

[DEMO]

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What a blend shape *cannot* do

- Change connectivity
  - eg. change res, remeshing
- Change topology
  - breaking apart, fusing parts
- Change attributes
  - (eg color…)
- Change textures
  - Use a texture animation instead, maybe?

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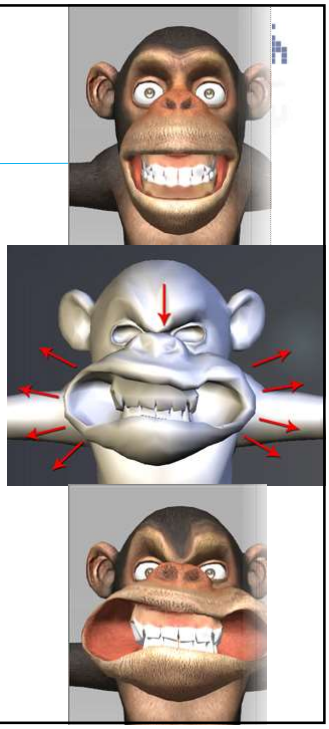
Blend shapes: authoring

Manual authoring:

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



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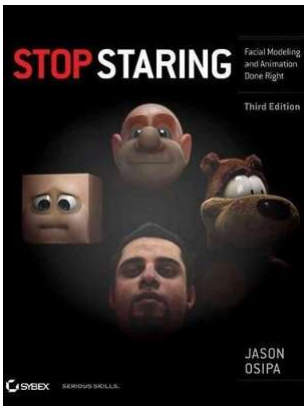
Blend shapes: authoring

- 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”

[VIDEO]

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Blend shapes: pro and con

- ☺ Flexible, expressive, huge number of DOF… too much?
  - ☹ RAM cost
  - ☹ Work intensive to construct

(but, not as bad as old sprites,

because (1) sharing of connectivity, textures, attributes
(2) keyframes / interpolation!

- ☺ Easy to use / efficient, once they are built
  - just define global weights

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Blend shapes: open challanges

- Capturing from a stream of meshes
- Compression
  - eg: prediction + store corrections + Huffman
- Streaming
- LOD-ding

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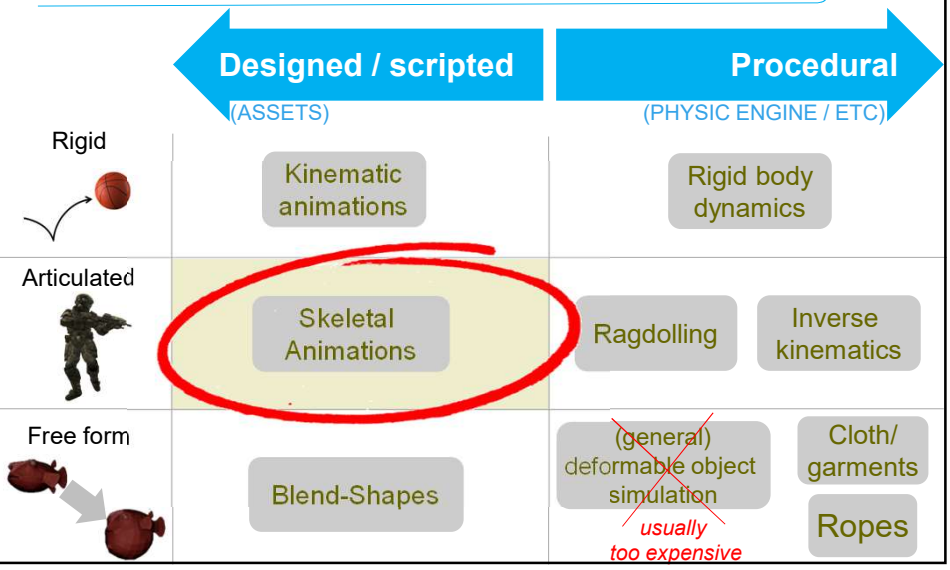
Animations in games (of 3D Solid Objects)



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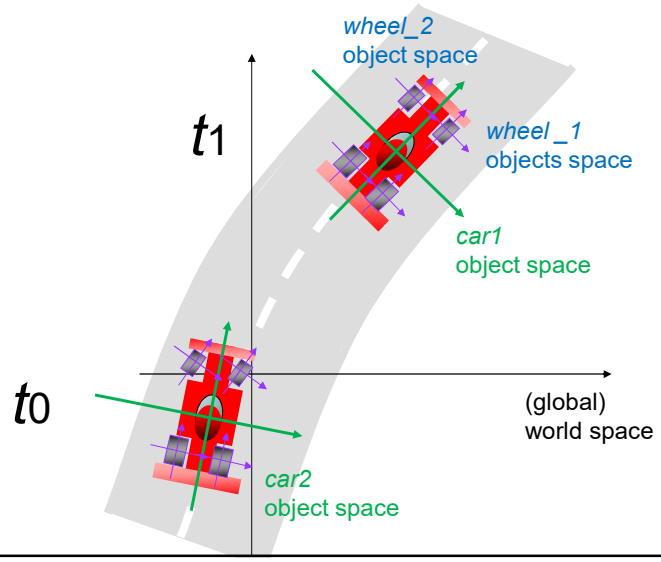
Step by step…
Kinematic animations



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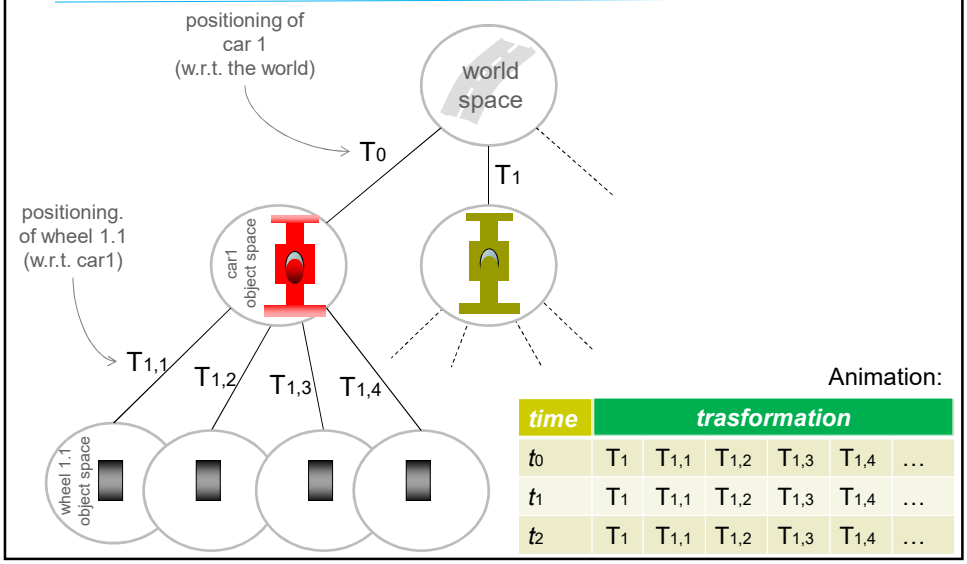
Step by Step…
Kinematic animatios



Animation:

time	trasformation					
t_0	T_1	$T_{1,1}$	$T_{1,2}$	$T_{1,3}$	$T_{1,4}$	…
t_1	T_1	$T_{1,1}$	$T_{1,2}$	$T_{1,3}$	$T_{1,4}$	…
t_2	T_1	$T_{1,1}$	$T_{1,2}$	$T_{1,3}$	$T_{1,4}$	…

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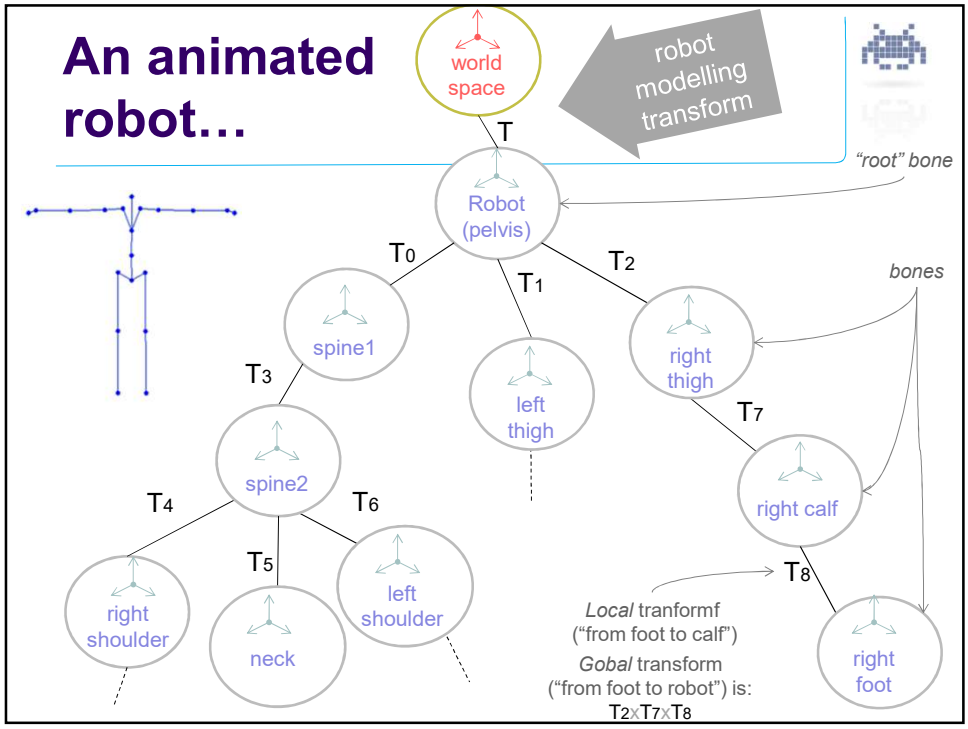

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Step by step…

From a bunch of pieces…

- So far: one mesh in each "bone"
  - (e.g., car-cockpit, car-wheel)
- Ok, for simple structure
  - (like a car, a windmill…)
- What about a humanoid "robot" with 25-60 "bones"?
  - Individual meshes for arms, forearms, legs… three meshes for each finger?
  - Possible, but…
    - inefficient to render (many "draw calls")
    - uneasy to manage (lots of files?)
    - a nightmare to design / author ("sculpt me a nice looking calf")
    - and… looks right only for robots (each object rigid!)

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… to articulated models…

- Idea: one mesh, but *skinned*
  - 1 mesh per the entire character
  - a new attribute per vertex: *index of bone*
  - the 3D model can now be animated!

"Skinning" of the mesh (1st version).

- Orthogonality models / animations!
  - that is:
    - one skinned mesh: runs with any animations
    - one skeletal animation: can be appliecable to any model
  - (as long as they use the same RIG – set of bones)
  - →500 models + 500 animations = 1000 things in GPU RAM
    - not: 500x500 combinations
- The tasks required from digital artists:
  - "rigging": define the skeleton inside the mesh (riggers)
  - "skinning": define vertex-to-bone links, i.e. the skinning (skinners)
  - "animation": define the actual animations(animators)

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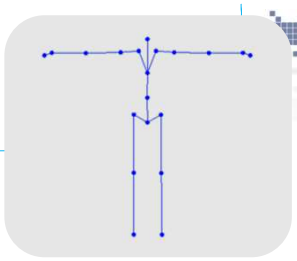
Rig (or skeleton): data structure 1/2



- A tree of **bones**
- bone:
  - Vectorial frame (space) used to express pieces of the animated model
  - eg, for a humanoid: *forearm, calf, pelvis,* …
  - (rigging bone != biological bones)
- Space of the *root* bone =(def)= object space (of the entire character)
- How many bones in a skeleton of a humanoid:
  at least: 22-24 (typically)
  reasonable: ~40 bones.
  very high: few 100s

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Pose: data structure

One trasformation for each bone *i*

- Local transform: (of bone *i*)
  - from: space of one *i*
  - to: space of bone father of *i*

often, only the rotation component

("fixed length bones": translations defined once and for all by the skeleton)

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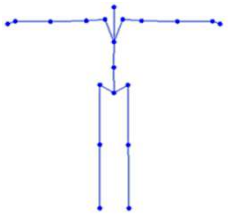
Rig (or skeleton): data structure 2/2

1. **Hierarchy** (tree) of **bones**
   - a **root bone** on top



2. A special **pose** «**rest pose**»
   - 3D models are to be modelled in this pose
   - also: «T-pose», «T-stance»,
     - same resason why T-shirts are called T-shirts ;)

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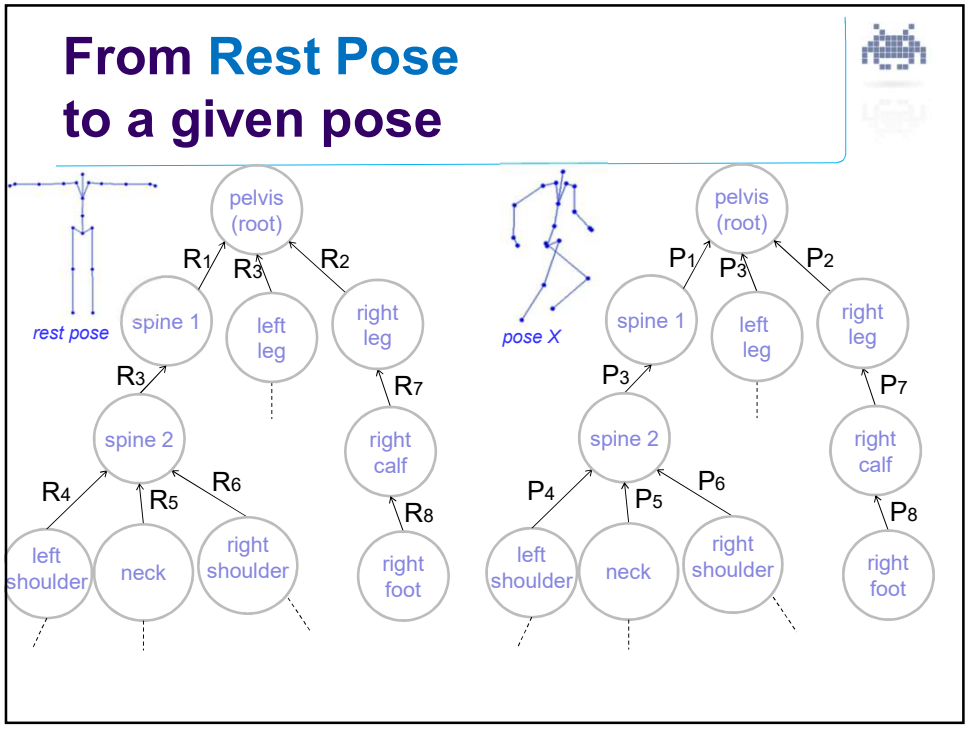
From Rest Pose
to a given pose
rest pose
pose X
pelvis (root)
spine 1
spine 2
left leg
right leg
right calf
right foot
left shoulder
neck
right shoulder
R1
R2
R3
R4
R5
R6
R7
R8
P1
P2
P3
P4
P5
P6
P7
P8

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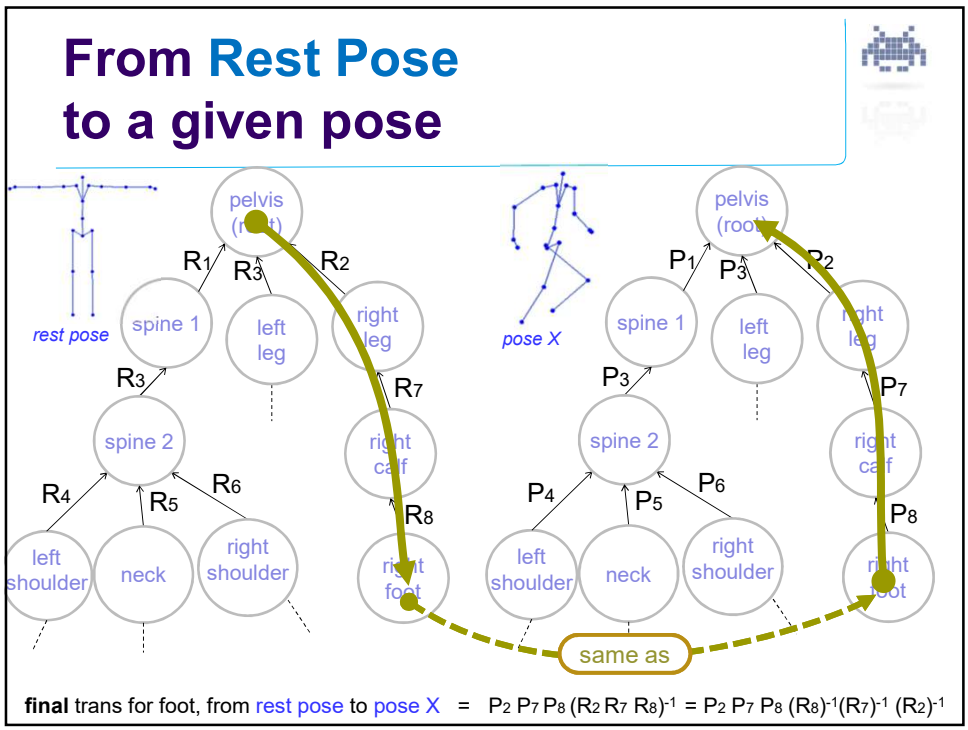
From Rest Pose
to a given pose
rest pose
pose X
same as
final trans for foot, from rest pose to pose X = P2 P7 P8 (R2 R7 R8)-1 = P2 P7 P8 (R8)-1(R7)-1 (R2)-1

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Bone transforms in a pose. E.g. for «right foot» bone:

- **Local** Transform: P_8
  - from *«right foot»* to *«right lower leg»*
- **Global** Transform: $P_2\ P_7\ P_8$
  - from *«right foot»* to *«character»*
  - uses the Hierarchy of the **Skeleton**
    - once global t are computed, Hierarchy's no longer needed!
- **Final** Transform: $P_2\ P_7\ P_8\ R_8^{-1}\ R_7^{-1}\ R_2^{-1}$
  - from *«character»* in rest pose to *«character»* in dest. pose
  - uses the Rest Pose of the **Skeleton** (R_1 … R_N)
    - once it's computed, Rest Pose no longer needed either!

the object frame of the character, i.e. the frame of the **root bone**

the space where **mesh vertices** are defined!

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Pose (for a given rig) : data structure

- pose = array of (local) transforms
  - it's defined for one given rig
  - RAM cost: n_bones x bytes_for_a_tranform

Osso *i*	Trasform[*i*]
#0 (pelvis) [root]	L[0]
#1 (spine)	L[1]
#2 (chest)	L[2]
#3 (shoulder sx)	L[3]
…	…
#10 (calf)	L[10]
…	…

Local Transform

It includes:

- a Rotation: always!
- a Translation: maybe
  If not, use the one defined in the **rest pose** of the rig.
  ==> a pose cannot redefine bone *lengths*.
- a Scaling: maybe
  If not ==> a pose cannot redef the *size* of the body part.

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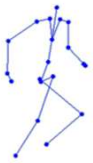
Pose (for a given rig) : data structure in GPU

- pose = array of **final** transforms
  - it's defined for one given rig
  - RAM cost: n_bones x bytes_for_a_tranform



Osso *i*	Trasform[*i*]
#0 (pelvis) [root]	F[0]
#1 (spine)	F[1]
#2 (chest)	F[2]
#3 (shoulder sx)	F[3]
…	…
#10 (calf)	F[10]
…	…

computed in preprocessing e.g. as:
$L[2]\ L[7]\ (R[7])^{-1}\ (R[2])^{-1}$

local transforms of *this* pose

local transforms of *rest* pose

final transforms

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Skeletal Animation : data structure (CPU or GPU)

- 1D Array of **pose**s (the keyframes of the ani)
  - RAM cost:
    (num keyframes) x (num bones) x (transform size)
  - Each pose assigned to time d*t*
    - delta from start of animation t_0
  - Sometime, looped
    - interpolation 1st keyframe with last

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Step by step…

1. From a bunch of pieces…

- one separate mesh in each “bone”
  - “calf” mesh, “head” mesh, “right-forearm” mesh…

… to articulated models…

- 1 mesh for the entire character
- in each vertex, a link to a bone

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… to articultated *defomable* models.

- Idea: link each vertex to >1 bones
- Transform of the vertex:
  - interpolation of the trasformations associated to the linked bones
  - weights of the interpolation: defined per-verex
- Data structures: per-vertex attributes
  - store:
    - [bone index , weight] x N_{max}
    - (typically, N_{max} = 4 or 2, see later)

the “Skinning” of the mesh
ver 2.0
(the real one)

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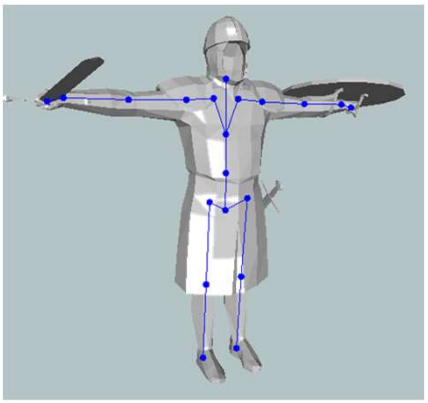
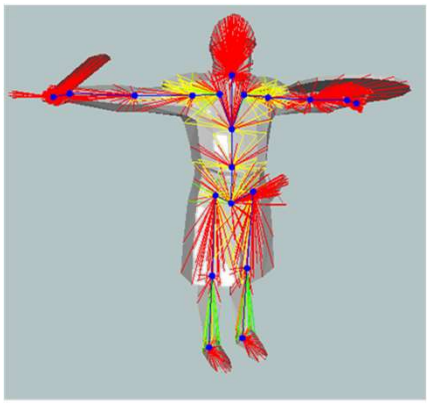
Content creation Tasks: Rigging & Skinning (of a 3D mesh)



Rigging – authoring of a rig
defining the skeleton
(often: also of the controls
to define poses for it)



Skinning – authoring of the skinning
"paint" of (weighted) links
between vertices and bones

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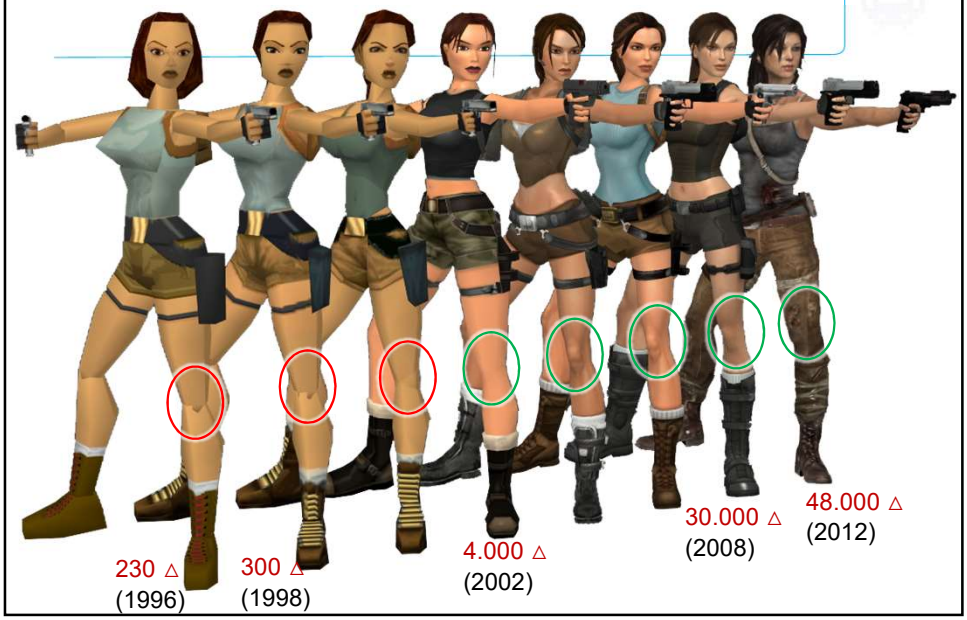
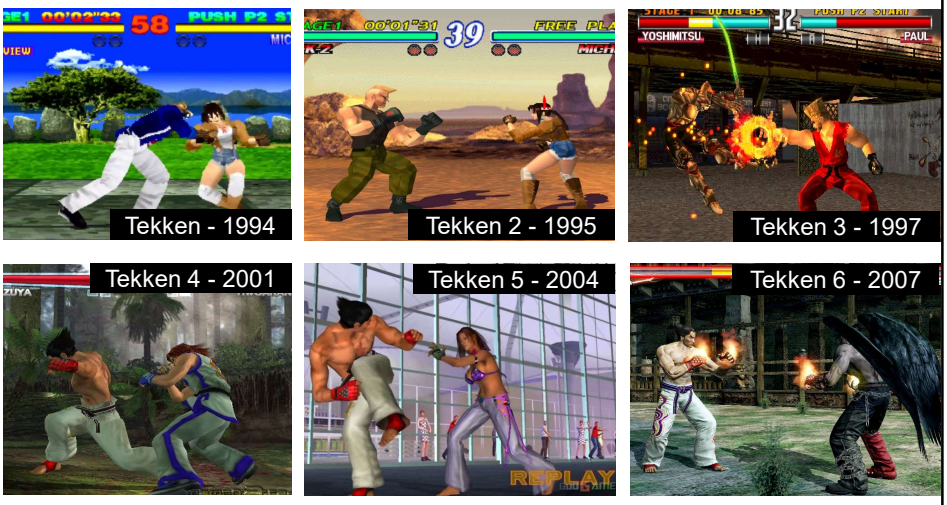
(this story actually happened)



75

(this story actually happened)



76

(this story actually happened)

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Skinned Mesh: data structure

- A Mesh with a **skinning**
  - A **per vertex attribute**
  - Stored per vertex:
    - [bone indexd , weight] x N_{max} times
    - example:

Vertex **120** →

Bone Index	Weight
9 *(Spine B)*	**0.4**
13 *(Chest)*	**0.1**
15 *(Shoulder Right)*	**0.4**
16 *(Forearm Right)*	**0.1**

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N_max = How many bone links for each vertex

- It's a call of the Game engine!
- typical used value:
  - **1** (rigid pieces) (bonus: no need to store weights)
  - **2** (cheap, e.g. for mobile games)
  - **4** (top quality – standard)
  - more: never in games (currently)
- Can one lower N_{max} ?
  - yes, in preprocessing
    (e.g. task for a un game tool)
  - e.g.: Unity does this during skinned mesh import
    (if asked)

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(but why put an hard-bound on bone links?)

- Reduces performance cost
  - N_{max} tranforms need be interpolated in GPU
    - in vertex shader
  - GPU = no good at control:
    - always uses exactly N_{max} trasf
    - unused bones: weight = 0
- Reduces GPU RAM cost
  - not only fewer data to store, but:
  - fixed leght arrays: the only way in GPU
    - N_{max} (index,weight) pairs
    - even where fewer are locally needed (e.g. 1 bone, weight automatically 1)

es:

Bone Index	Weight
9 *(Head)*	1.0
--	0.0
--	0.0
--	0.0

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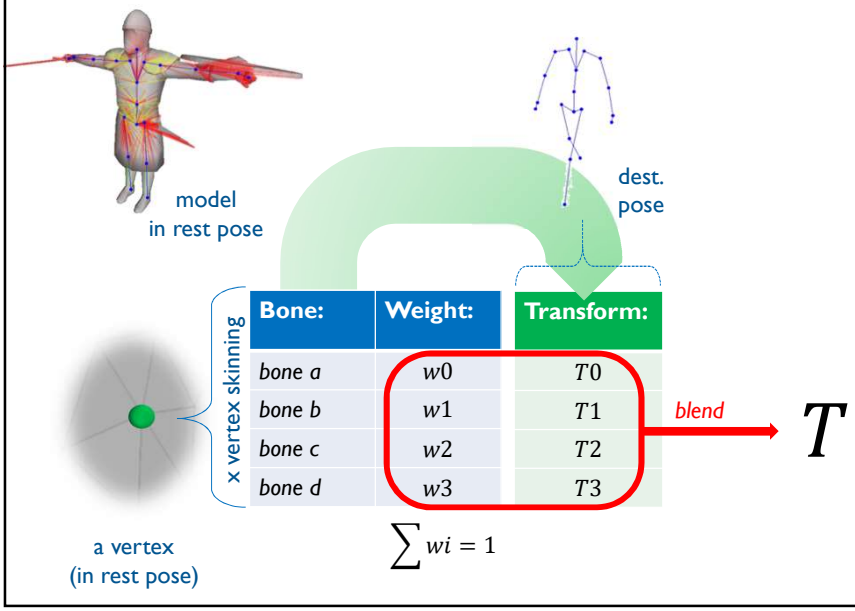
Skinning - how it works (in GPU)



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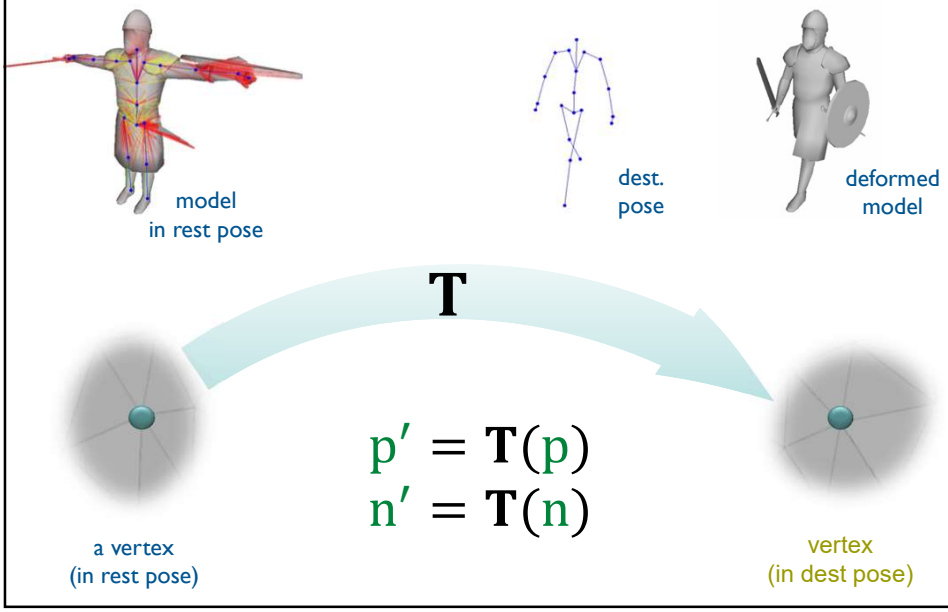
Skinning - how it works (in GPU)



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GPU real time Skinning – two variants

(a choice of the rendering engine)

Bone:	Weight:	Transform:
bone a	$w0$	$T0$
bone b	$w1$	$T1$
bone c	$w2$	$T2$
bone d	$w3$	$T3$

blend → T

How this is done?

- linear interpolation of *matrices*:
  "Linear Blend Skinning"
  (old school, still very much used)
- *quaternion* based interpolation:
  "Dual Quaternion Skinning"
  (more complex, fewer artifacts)

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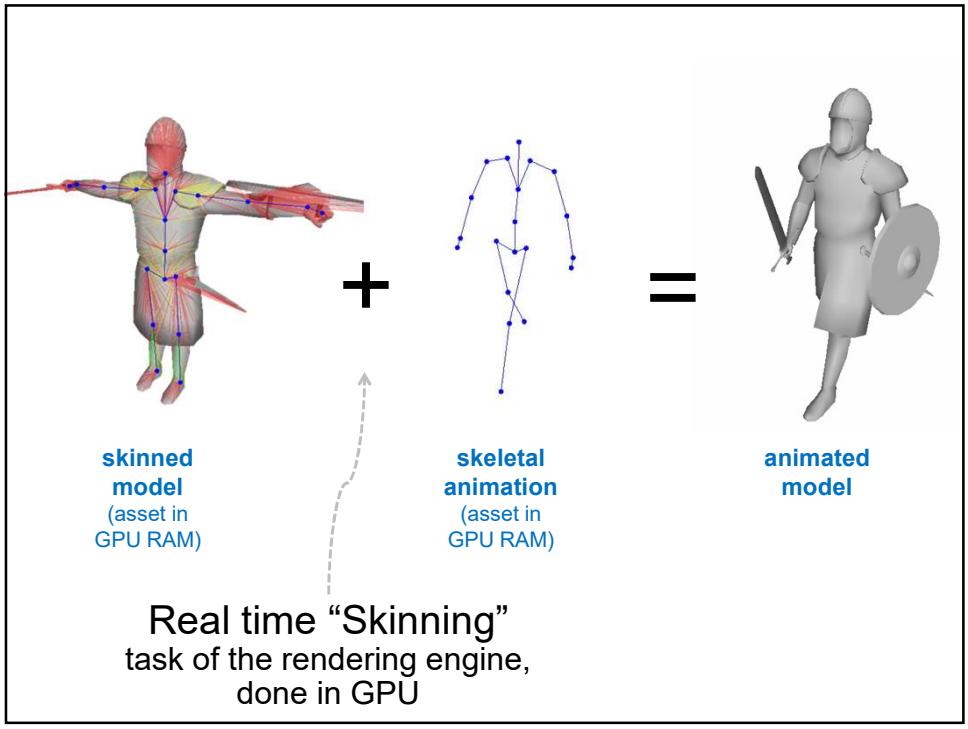
+
=
skinned model (asset in GPU RAM)
skeletal animation (asset in GPU RAM)
animated model
Real time “Skinning”
task of the rendering engine, done in GPU

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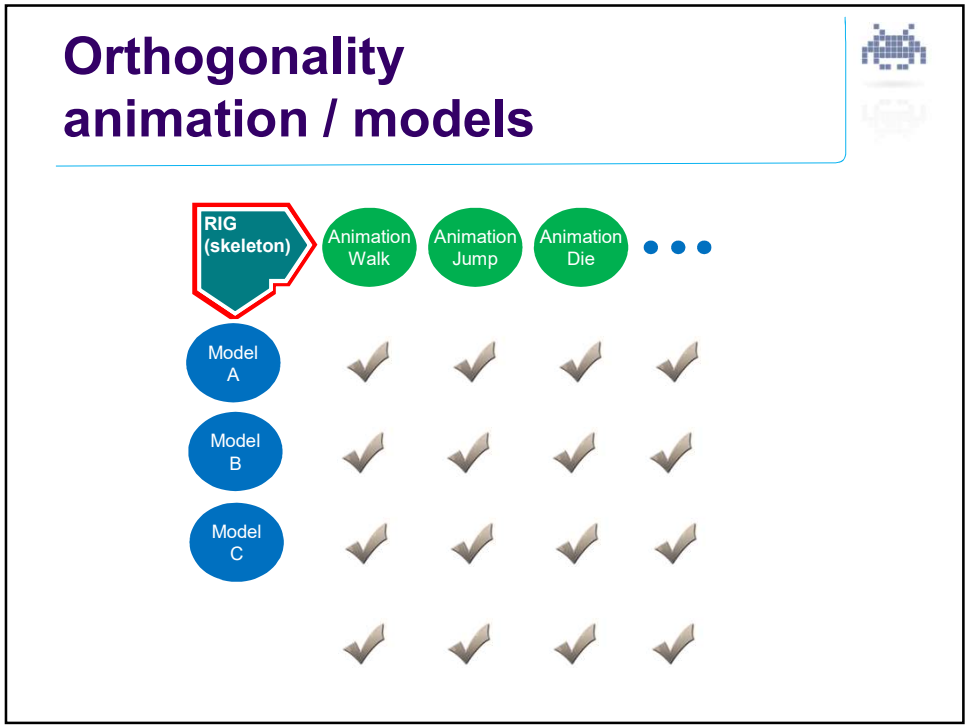
Orthogonality animation / models
RIG (skeleton)
Animation Walk
Animation Jump
Animation Die
Model A
Model B
Model C

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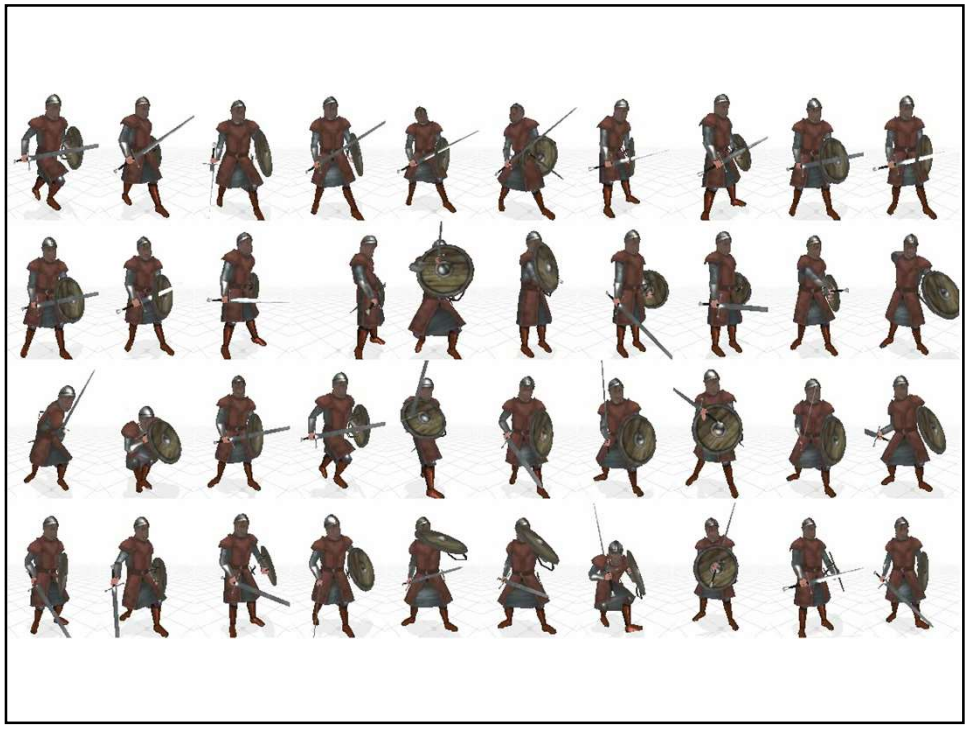

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(recap) Skeletal animations: 3 Assets (data strcutures)

- **Rig** (or skeleton)
  - Tree di bones (ossa)
  - ∀ bone => reference frame (in rest pose)
    - (reference frame root bone = objects space)
- **Skinned** 3D Model
  - Mesh with links: vertices => bones
  - ∀ vertex: attributes: [bone index , weights] x N_{max}
- **Skeletal animations**
  - Sequence of keyframe poses
  - ∀ pose, ∀ bone = a local transform

example of file formats (for all three):

- **.SMD** (Valve), **.FBX** (Autodesk), **.BVH** (Biovision)

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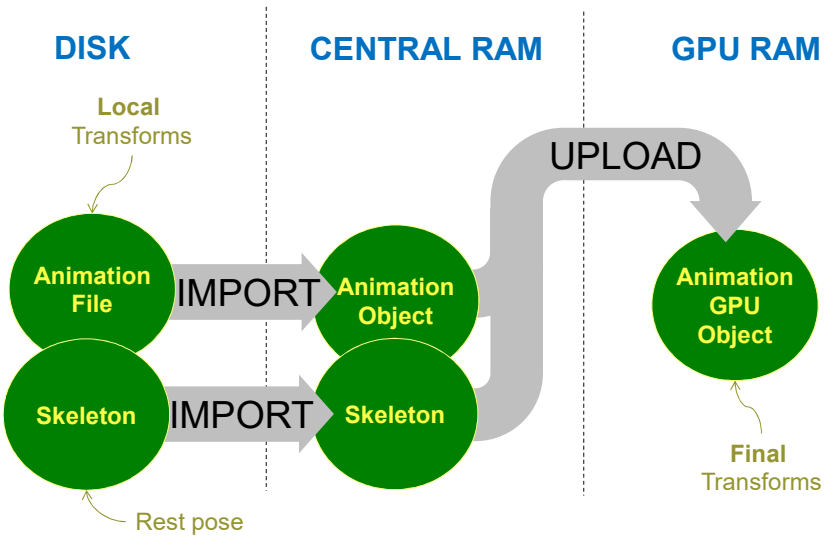
Life of Animation Assets in a Game Engine



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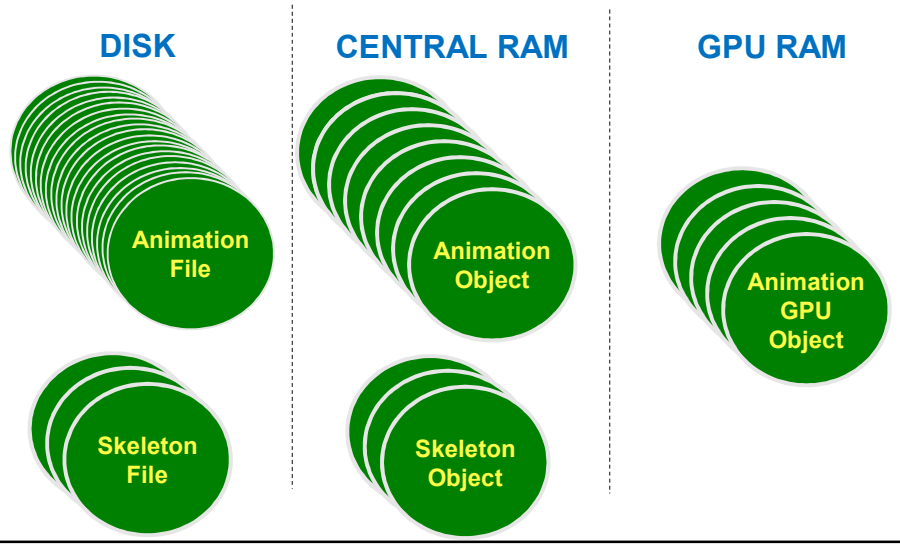
(Once again, Memory Management)



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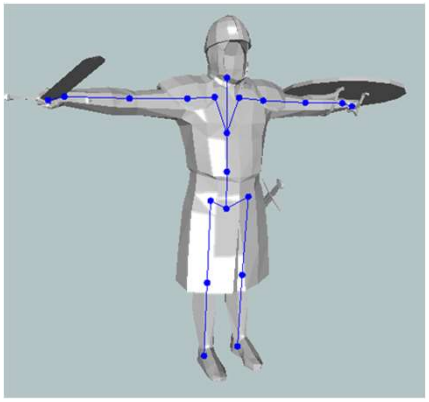
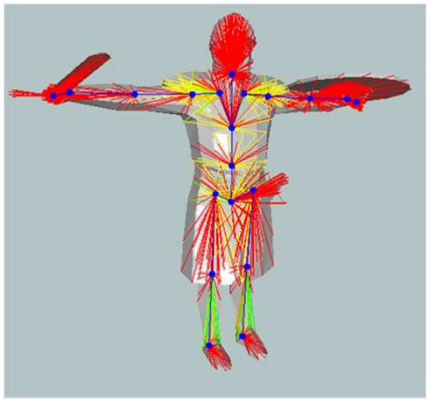
Content creation Tasks: Rigging & Skinning (of a 3D mesh)



Rigging – authoring of a rig
defining the skeleton
(often: also of the controls
to define poses for it)



Skinning – authoring of the skinning
"paint" of (weighted) links
between vertices and bones

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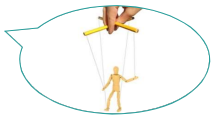
Content creation Tasks: Rigging & Skinning (of a 3D mesh)

Digital modeller task! (helped / replaced by automatic algorithms)

- Rigging :
  - define a skeleton (with a rest pose)
  - inside one mesh, (or a set of meshes: a *shared* rig)



- Skinning (of a mesh):
  - painting link vertex-bones

Ditigal animator task

- Animation (of a rig)
  - authoring of (skeletal) animations
  - (More about this later)

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Skeletal animations: authoring / obtaining them

- Manual editing
  - digital animators
  - help from: IK (in animation interfaces), physical simulations (for “secondary” animations)
- From physics simulation
  - just use the right set of constraints! (easy, in Verlet)
  - in preprocessing (bake them) or on the fly: “RAGDOLLING”
- Or…

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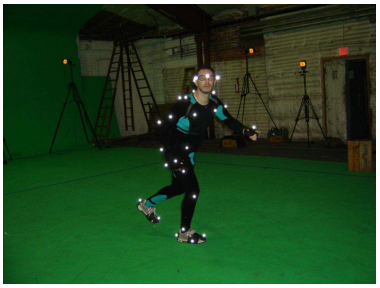
Skeletal animations: authoring / obtaining them

- Motion capture:



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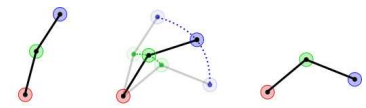
Interpolation poses

- any two poses can be interplated!



- just interplolate the per bone transform
- (note: requires recomputation of final transf from local ones)

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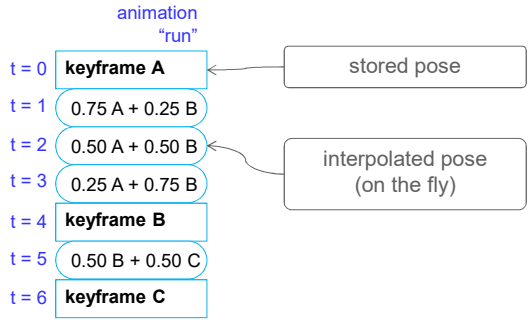
Pose = keyframe

- Compress animations



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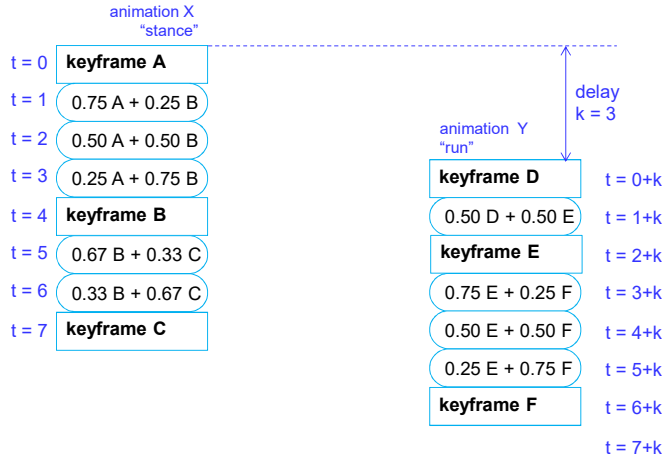
Interpolation of poses (at runtime): transition between animations

- Eg: from *stance* to *run*



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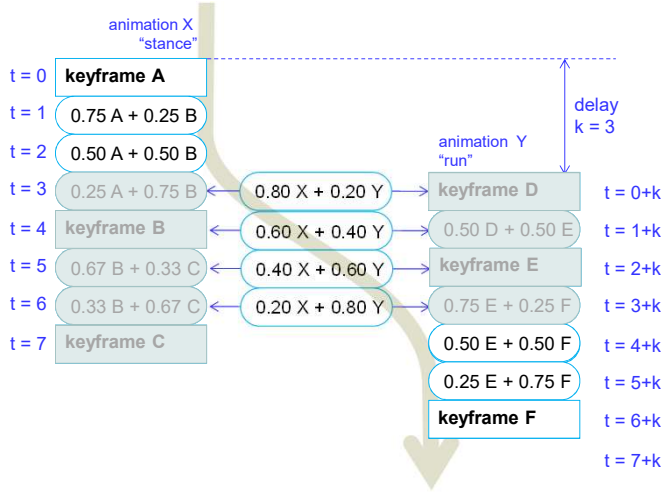
Interpolation of poses (at runtime):
transition between animations

- Eg: from *stance* to *run*



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Applying poses:
Dual Quaternion Skinning

- A variant:
  per-bone transforms are stored as
  dual quaternion
  - isometries only
  - (arguably) better quality
    - (better interpolation)
  - > GPU cost
    - (necessary ops: ~ +50%)
- LBS (Linear Blend Skinning) or DQS?
  - a call of the game engine

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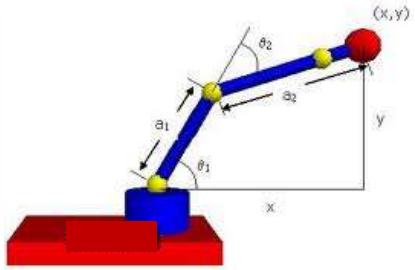
Forward kinematic VS inverse kinematic

- (in robotics)



Forward kinematics:
«from angles (and dists) to (x,y)»

VS

Inverse kinematics:
«from (x,y) (and dists) to angles»

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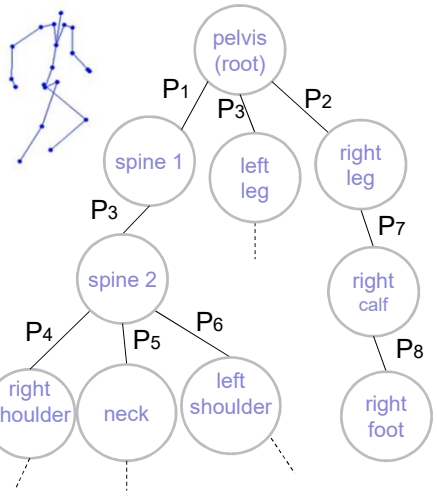
Inverse Kinematic (IK): an useful tool

- Forward kinematics:
  - "given local transfer $P_1, P_2 \dots P_N$, (as angles) where does the foot go?"
  - (one solution, trivial)
- Inverse kinematics
  - "if I need the foot to be in pos p, how to set $P_1, P_2 \dots P_N$, ?"
    - (under constraints, e.g. DoF at joints)
  - (no one solution, not trivial)



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Inverse Kinematic (IK): an useful tool

- Two uses:
  - in preprocessing (helping the task of the animator)
  - in real time (done by the game engine)
    (e.g. in unity: API in scripts)
- Examples of real-time uses:
  - Exact positioning of feet on ground
  - Exact positioning of hand to object to be grabbed
  - Hands need to be joined
    (e.g. 2-handed weapon wielding)
    - (e.g. making the system correct for small changes in bone lengths)
    - (e.g. during interpolated keyframes)
  - etc.

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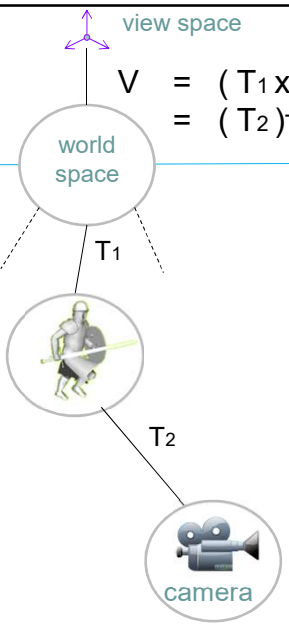
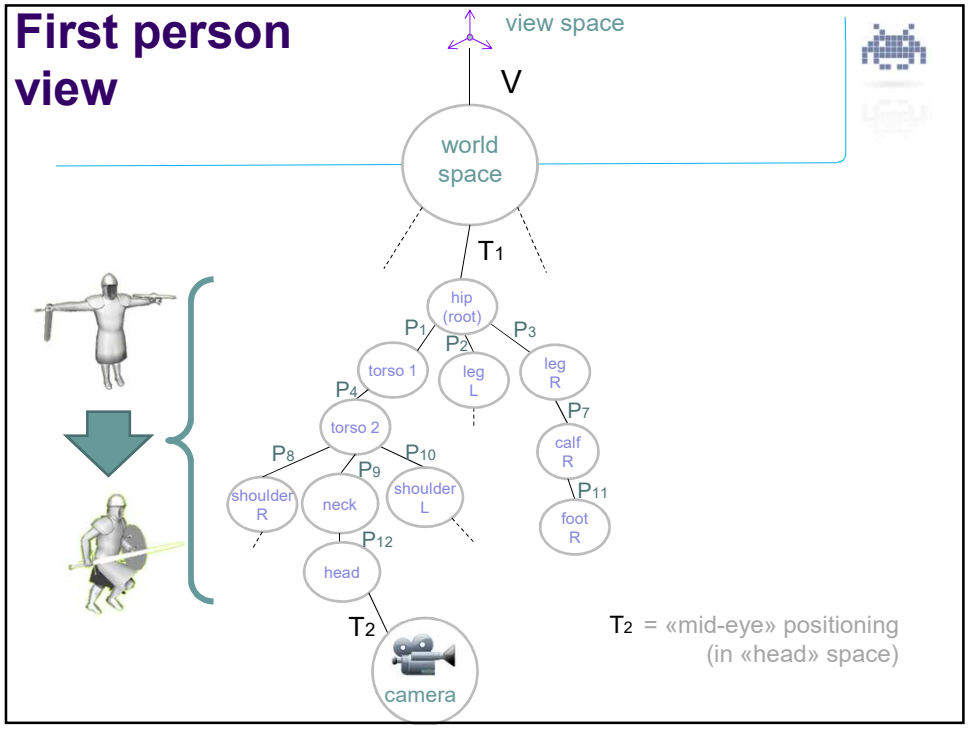
Third person view



106


First person view
view space
V
world space
T1
hip (root)
P1
P2
P3
torso 1
leg L
leg R
P4
torso 2
P7
calf R
P8
P10
P9
shoulder R
neck
shoulder L
P11
foot R
P12
head
T2
camera
T2 = «mid-eye» positioning
(in «head» space)

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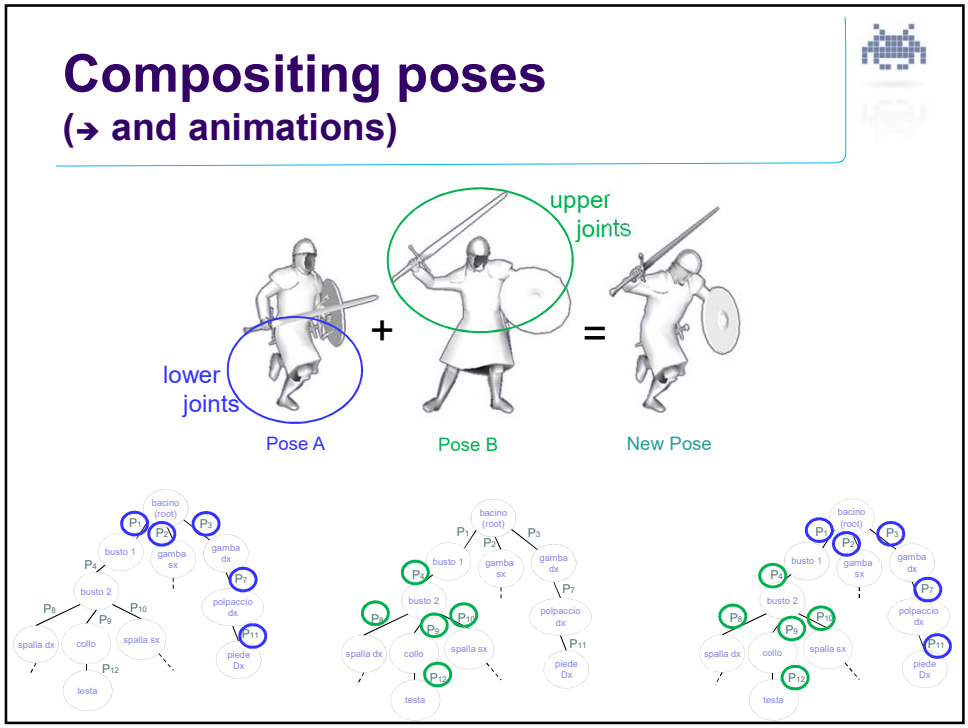
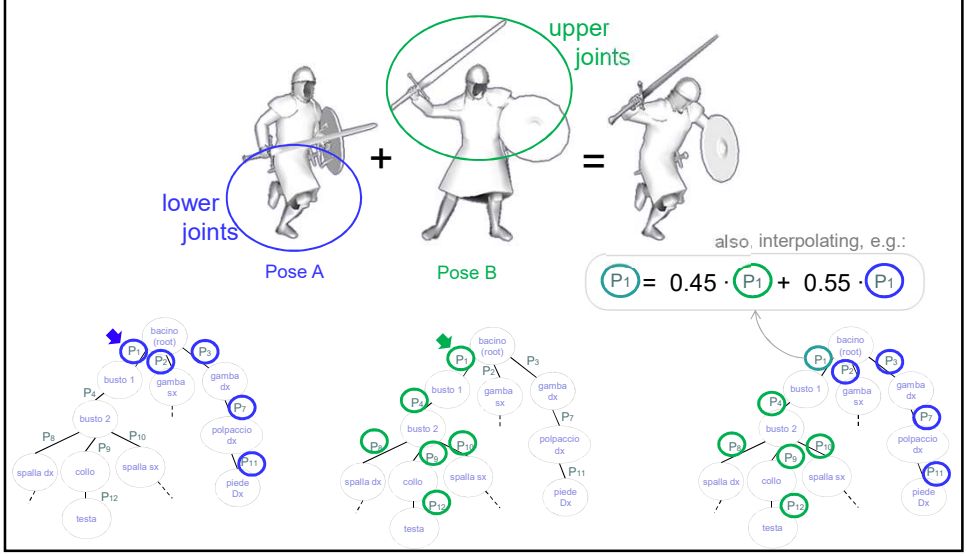

Compositing poses
(➔ and animations)
upper joints
lower joints
+
=
Pose A
Pose B
New Pose

108

Compositing poses
(➔ and animations)



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Compositing poses
(➔ and animations)

- Useful in different contexts:
  - e.g. different character parts following different ani (e.g. lower body: run. Upper body: aims/shoots/reload)
- Note:
  requires updating the final transformations
  - (after changing the local ones)
- Implementation note (Unity):
  - Unity does this with “Layers” in Animation Controller
    - Layer = a mask:
      which bones are driven by this animation?

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A few (pre)processing tasks for skeletal animations

- Compression
  - input: ani with N keyframes
  - output: ani with M<N keyframes
- Retargeting
  - input: Rig1 + (Skel animat for Rig1) + Rig2
  - output: (Skel animat for Rig 2)
- Building from a blend-shape animation
  - input: Blend-shape
  - output: Rig + Skinned Mesh + Anim
  - note: the opposite is a trivial («baking»)

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Compression of skeletal animations

- Objective: remove keyframes
  - the “redundant” ones
  - preprocessing task (e.g. as a game tool)
- Basic algorithm concept:
  - for each keyframe P_x
    - tentatively remove P_x
    - compute interpolated version P_i from remaining keyframes
      - (the prev and next ones)
    - if *distance*(P_i , P_x) > MAX_ERR then reinsert keyframe P_x

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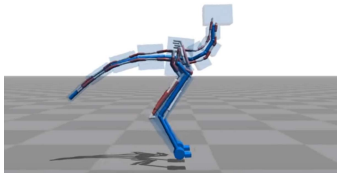
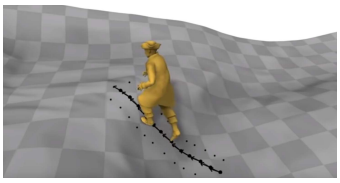
Research topic: apply ML to skeletal animations

- A very active area of research…



Flexible Muscle-Based Locomotion for Bipedal Creatures
Thomas Geijtenbeek, Michiel van de Panne, A. Frank van der Stappen
SIGGRAPH 2013



Phase-Functioned Neural Networks for Character Control
Daniel Holden, Taku Komara, Jun Saito
SIGGRAPH 2017

(Among MANY others)

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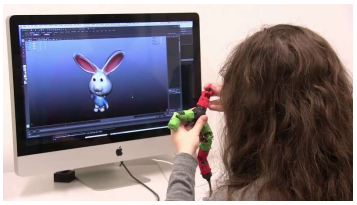
Research topic: better interfaces to author animations



Tangible and Modular Input Device for Character Articulation
Alec Jacobson, Daniele Panozzo, Oliver Glauser, Cedric Pradalier, Otmar Hilliges, Olga Sorkine-Hornung
SIGGRAPH 2014

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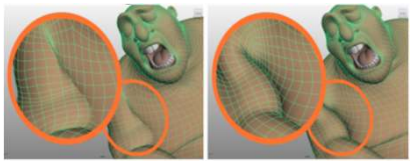
Research topic: Deformation beyond standard skinning



Efficient Elasticity for Character Skinning with Contact and Collisions
Aleka McAdams et al (Disney animation)
SIGGRAPH 11

Note: usually way more complex than direct methods (LBS / DQS).
More offline animation oriented than videogames

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Per-vertex animations VS Skeletal-Animations

- Per Vertex animations
  - can interpolate keyframes (but linear trajectories)
  - heavy in RAM
    - replications of normals / positions
  - light to render / compute
- Skeletal animations
  - can interpolate keyframes *better* (curved trajectories)
  - light in RAM
    - animations / models orthogonality
  - minor overheads
    - transform interpolation (x vert!)
    - updates final transoform before (unless can be baked)

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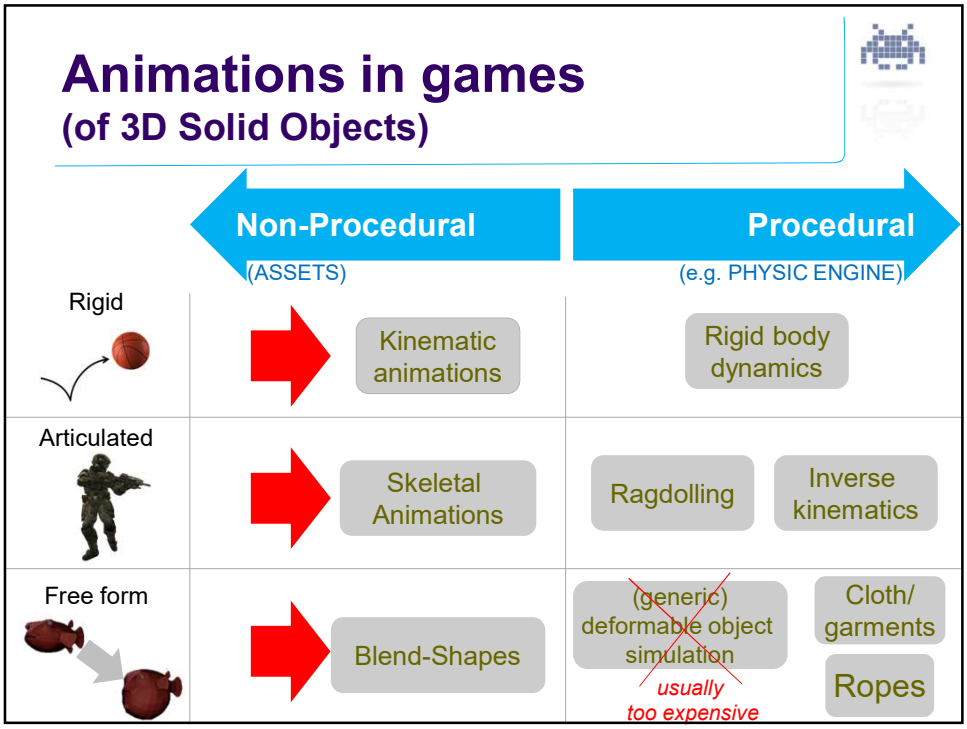
Animations in games
(of 3D Solid Objects)



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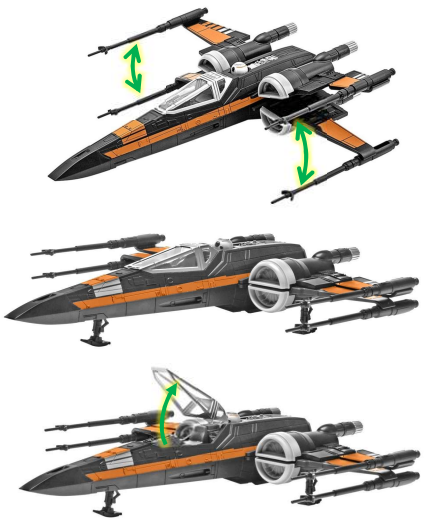
Non-procedural Animations: which one to pick?

- Which format to pick?

EXAMPLE:
say we want
a model capable of
doing this:



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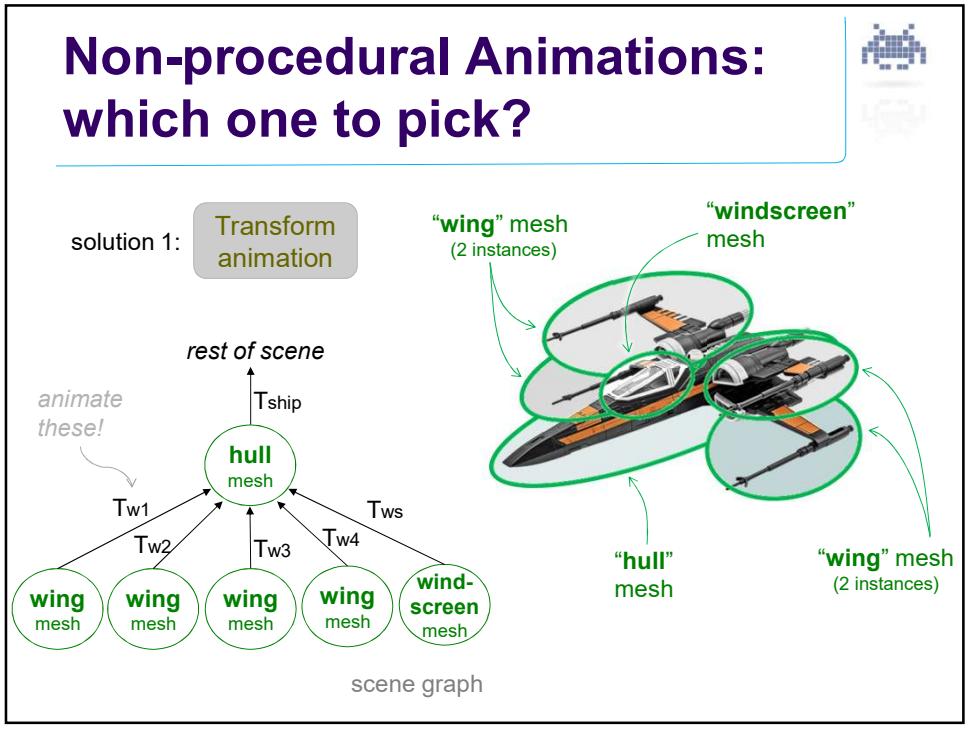
Non-procedural Animations: which one to pick?
solution 1:
Transform animation
"wing" mesh
(2 instances)
"windscreen" mesh
rest of scene
animate these!
Tship
hull mesh
Tw1
Tw2
Tw3
Tw4
Tws
wing mesh
wing mesh
wing mesh
wing mesh
wind-screen mesh
"hull" mesh
"wing" mesh
(2 instances)
scene graph

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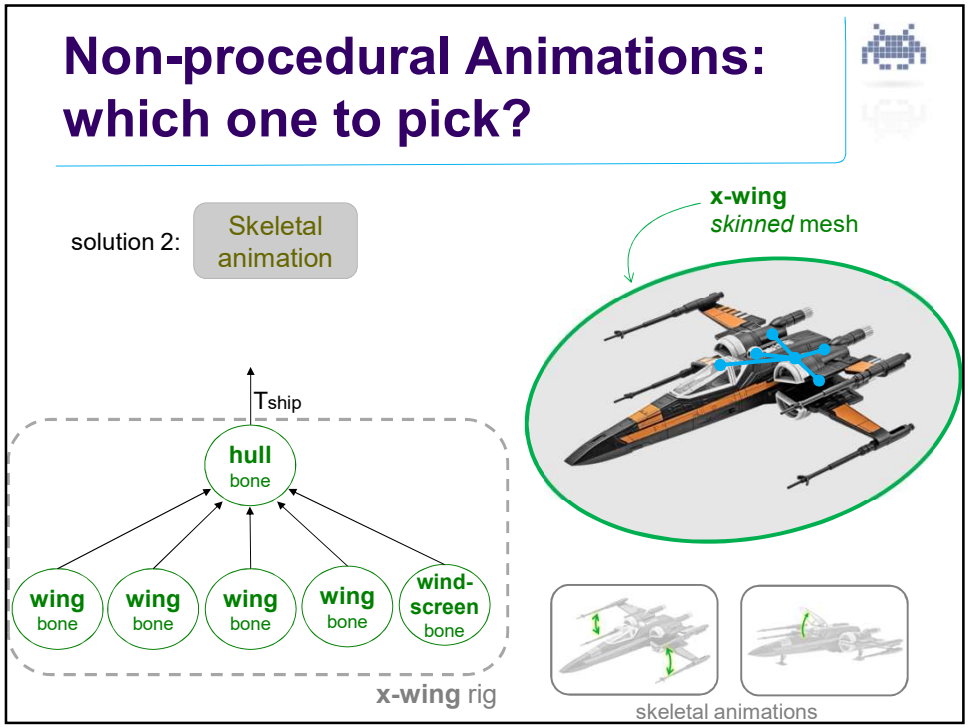
Non-procedural Animations: which one to pick?
solution 2:
Skeletal animation
x-wing
skinned mesh
Tship
hull bone
wing bone
wing bone
wing bone
wing bone
wind-screen bone
x-wing rig
skeletal animations

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Non-procedural Animations: which one to pick?

solution 3: Blend-shape

base shape | morph 1 | morph 2

"x-wing" blend-shape

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Non-procedural Animations: which one to pick?

In this example:

- **Animation of transforms (of the scenegraph)**:
  - *how:* 3 (rigid) meshes, 5 instances, animate scenegraph transforms
  - can reuse geometry for all wings: most compact on RAM ☺
  - simpler rendering
  - 5 separated draw calls! ☹
- **Skeletal animation**:
  - *how:* one rig + one skinned mesh + few skeletal animations
    - mesh skinning: single bone enough in this case
  - if very low poly mesh (few polys): a waste?
  - more taxing rendering (a bit) ☹
    - real time skinning on vertex any
  - single draw call! ☺
- **Blend shapes**:
  - *how:* blend shape with one base shape + 2 morphs
  - minimal impact
  - worst quality interpolation: linear → straight (non curved) paths
    - vertices on straight paths (unless, more shapes added)
  - heaviest on RAM ☹
    - (a waste of DoF!)
    - not important, if very low res
  - single draw call! ☺
    - but to different buffers each frame / or to a larger buffer

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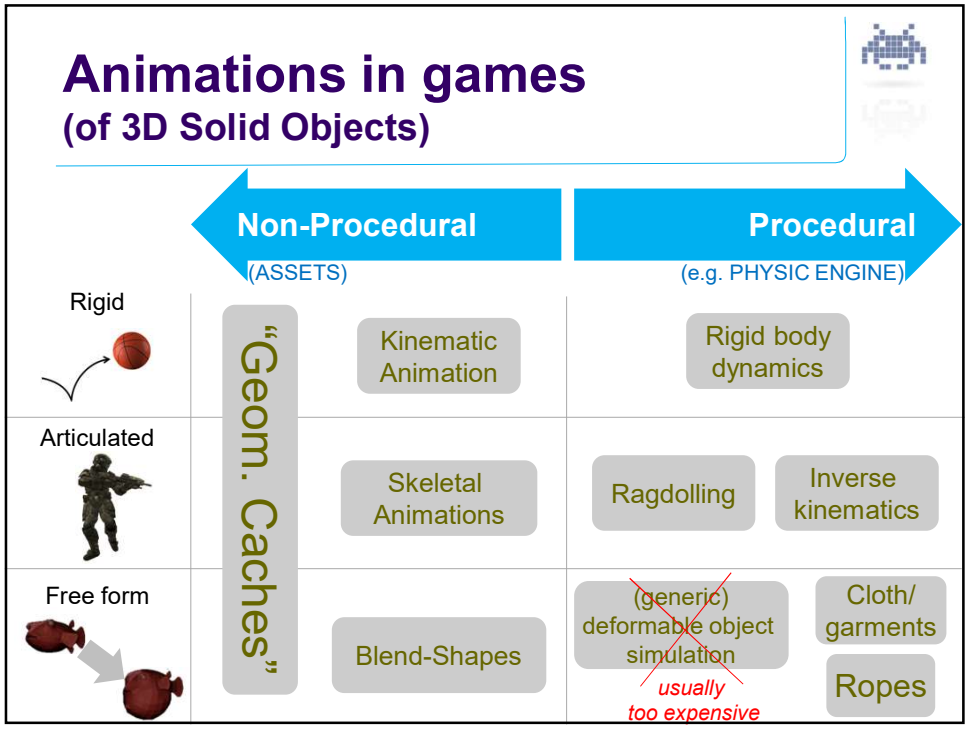
Animations in games
(of 3D Solid Objects)
Non-Procedural
(ASSETS)
Procedural
(e.g. PHYSIC ENGINE)
Rigid
Articulated
Free form
"Geom. Caches"
Kinematic Animation
Rigid body dynamics
Skeletal Animations
Ragdolling
Inverse kinematics
Blend-Shapes
(generic) deformable object simulation
usually too expensive
Cloth/ garments
Ropes

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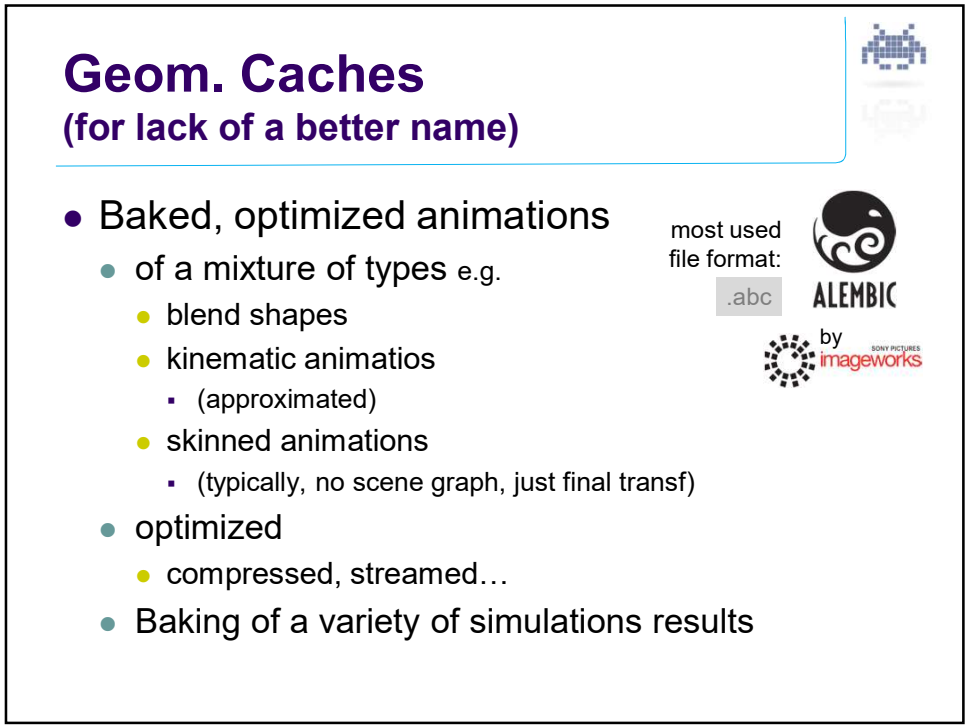
Geom. Caches
(for lack of a better name)
Baked, optimized animations
of a mixture of types e.g.
blend shapes
kinematic animatios
(approximated)
skinned animations
(typically, no scene graph, just final transf)
optimized
compressed, streamed…
Baking of a variety of simulations results
most used file format:
.abc
ALEMBIC
by imageworks

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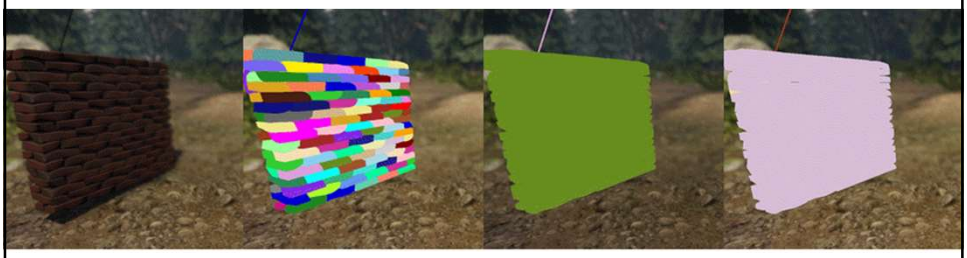
Geom. Caches
(for lack of a better name)

- Baked, optimized animations
  - of the appropriate types including mixtures



Input:
170 Meshes
88400 Verts

as Pre-made Tansforms:
Meshes: 170
Data rate: 0.13 MB/s
Draw calls: 170
(same ones each frame)

as a Blend Shape:
Meshes: 1, with N shapes
Data rate: 4.3 MB/s
Draw calls: 1
(different one each frame)

as a Skeletal Animation
Meshes: 1, w skinning (*)
Data rate: 0.13 MB/s
Draw calls: 1
(same one each frame)
(*) just 1 bone per vertex

Geometry Caches
(a subset of Alembic)

by CRYENGINE

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Animations
in Unity (+Mecanim) (notes)

- Assets (models, animation, skeletons) imported as formats:
  - fbx, collada
- Animation compression
  - available during import / builds
  - auto reduction of: num of links per vertex, num of keyframes … :
- «Animator Controller» module → deals with:
  - blending between animations: «transitions»
  - compositing animations: «layers»
    - e.g.: a layer overwrites upper body bones
  - and is nicely WYSIWYG (graph visualization)
- Inverse Kinematic: with scripts (`Avatar.SetIKPoistion`)
- Skeletons:
  - way 1: custom (imported as assets)
  - way 2: built-in standard humanoid skeleton provided
    - (~21 ossa)
    - simplified: rigging (predefined constrains), layers (predef. labelling)

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