1

MOTION CAPTURE DATA PROCESSING

- MOTION EDITING / RETARGETING
- MOTION CONTROL / GRAPH
- INVERSE KINEMATIC

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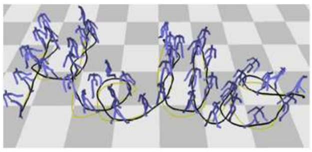

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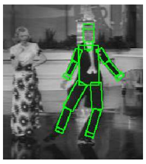
Motion capture data processing

From Data Capture to motion



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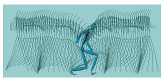
Overview: Motion data processing

In this course

- Motion editing
- Motion blending 2 animations
- Motion FSM/graph
- General Motion blending

Not in this course

- Motion segmentation
- Motion compression
- Etc.



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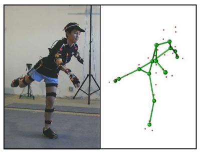
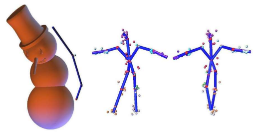
How do skeletons differ?

- Topology
  - number of bones
  - Connectivity of bones
- Joint Types
  - Bone lengths
  - Anatomical / skin relations
- Is spine in middle of body, or up the back?





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Subtle Skeletal Differences

- Rest Poses (design of a skeleton)
  - Zero Pose / Base Pose
  - Dress or Binding pose
  - Frankenstein Pose
  - Da Vinci Pose
  - Rest Pose (real pose of actor)
- Need to figure out how to get between these

Rest pose

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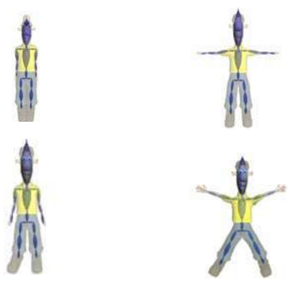
Subtle Skeletal Differences

- Same angles lead to different animation is rest pose is different

Rest pose

Animation with similar angles



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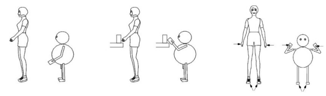

MOTION EDITING

Edit One Pose : IK, retargeting

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Retargeting

- capture motion on performer
  - **positions** of markers are recorded
- retarget motion on a virtual character
  - motion is usually applied to a skeleton
  - a skeleton is hierarchical
    - linked joints
  - need **rotation** data!
- need to convert positions to rotations

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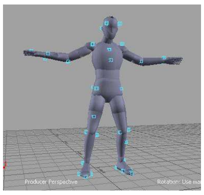
performer→ actor → character

- the **actor** is used to convert marker positions to rotational data
  - markers are handles on the actor
  - actor should have similar proportions as the **performer**
- joint rotations of the actor are applied to the character
- there are still issues with proportions



Alias Motionbuilder: actor and markers

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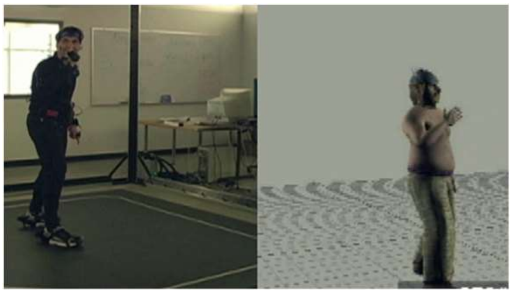
Retargeting problems: hand problem



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Problem of Hand or foot position!

- Often hand or foot positions do not match

[Images from Retargetting Motion to New Characters, Gleicher, Siggraph98]

- Need to find a position with hands on the box and feet in concordance with skeleton morphology
- Feet crossing the floor
- **Foot sliding**

➔Quick overview of inverse kinematic

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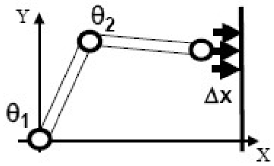
Inverse Kinematics

- Inverse Kinematics
  - Given effectors positions, find a posture(=angles)
- Non-linear problem (position vs. angles)
  - Possibility of no or multiple solutions



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Forward Kinematics

- We will use the vector:

$$\Phi = [\varphi_1 \quad \varphi_2 \quad \ldots \quad \varphi_M]$$

to represent the array of M joint DOF values

- We will also use the vector:

$$\mathbf{e} = [e_1 \quad e_2 \quad \ldots \quad e_N]$$

to represent an array of N DOFs that describe the end effector in world space. For example, if our end effector is a full joint with orientation, **e** would contain 6 DOFs: 3 translations and 3 rotations. If we were only concerned with the end effector position, **e** would just contain the 3 translations.

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Forward Kinematics

- The forward kinematic function f() computes the world space end effector DOFs from the joint DOFs:
  - Forward kinematic is often easy to compute

$$\mathbf{e} = f(\mathbf{\Phi})$$

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Inverse Kinematics

- The goal of inverse kinematics is to compute the vector of joint DOFs that will cause the end effector to reach some desired goal state
- In other words, it is the inverse of the forward kinematics problem
  - $f^{-1}()$ usually isn't easy to compute

$$\mathbf{\Phi} = f^{-1}(\mathbf{e})$$

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Inverse Kinematics

Inverse Kinematics: many approaches

- Analytic method [IKAN, Badler]
  - Geometric based, fast
  - Ok only for few joints
- Numeric solution
  - Iterative process
  - Expensive
  - Flexible (constraints)
  - Minimization problem

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Editing One Pose

See the course on IK

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Back to Retargeting problems

- IK may help for hand and foot but …
- many other problems than hand or foot!

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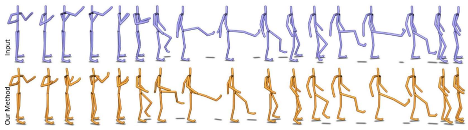
MOTION EDITING

Edit One Animation



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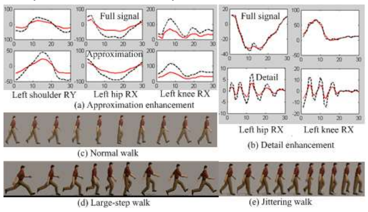
Recap on motion!

- Motion is a function of time
  - Given time, provide a pose
  - Often represented as samples
- Sparse samples + interpolation
  - Dense samples (at frames)
  - How to manipulate sets of samples?



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The General Challenge

What you get is not what you want!

- You get observations of the performance
  - A specific performer
  - A real human
  - Doing whatever they did
  - With the noise and "realism" of real sensors
- Want something else
  - But need to preserve original
  - But we don't know what to preserve
  - Can't characterize motion well enough

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Three Problems

- Where does X live in the data?
  - Where X ∈ {style, personality, emotion, …}
  - The things to keep or add

- Small artifacts can destroy realism
  - Eye is sensitive to certain details
- How to *specify what you want ?*

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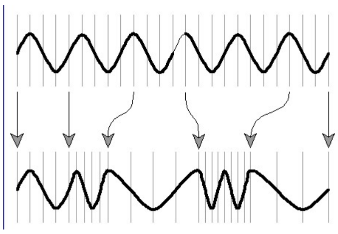
Manipulating motion

- Manipulate time: Motion slower or faster
  - m(t) = m0(f(t))
  - f : R - > R "time warp"

VIDEO

- Time scaling
  - f(t) = k t
- Time shifting
  - f(t) = t + k
- Time warping
  - Interpolate a table
  - Align events



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Manipulating motion

- Manipulate value
  - m(t) = f(m0(t))
  - f : Rn- > Rn
- Scale?
  - For instance each angles x 2 → Exagerate motion
- Shift?
- Convole (linear filter)
- "Add" to another motion
  - m(t) = m.(t) + a(t)

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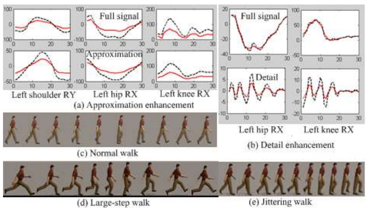
Noise Removal: Signal Processing

- Noise comes from errors in process
  - Sensor errors
  - Fitting errors
  - Bad movements
- Nose is “data” that we don’t want



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Where’s the Noise?

- Sometimes identification is easy
  - Clearly wrong (foot through floor)
  - Marked wrong (missing data - gaps)
- More often, need to guess
  - Might be a subtle twitch…
  - Might be person shaking…
  - Might be sensor errors…

➔simply apply a filter ?

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Important Intuition

- High Frequencies are Important!
- Always significant
  - Impact
  - Rapid, sudden movement
  - …

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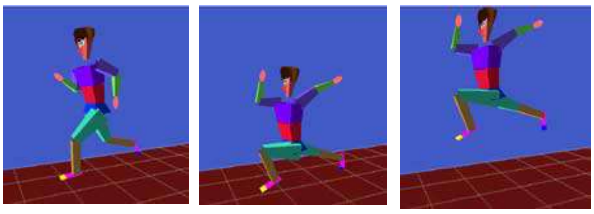
Signal processing [Unuma95]

- Fourier series
  - Coefficient motion parameters (emotion, gait)



Exaggerate jump by scaling low frequency

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Motion Signal Processing [Bruderlin95]

- Foreach channel of each joint

Input signal N values: 10 | 14 | 16 | 20 | 22 | 24 | 28 | 22 | … | …

N/2 values: 12 (± 2) | 18 (± 2) | 23 (± 1) | 25 (± 3) | … ~high frequency

N/4 values: 15 (± 3) | 24 (± 1) | …

…

1 value: 19.5 (± 4.5) ~low frequency

G = white values; L=red values

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Motion Signal Processing [Bruderlin95]

- G : (left) white value of previous slide
- L : (right) red value of previous slide

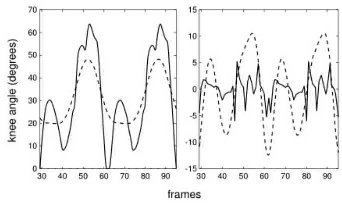

Figure 2: Left: lowpass G_0 (solid) and G_3 (dashed; B-spline kernel of width 5); right: bandpass L_0 (solid) and L_2 (dashed) of the sagittal knee angle for two walking cycles.

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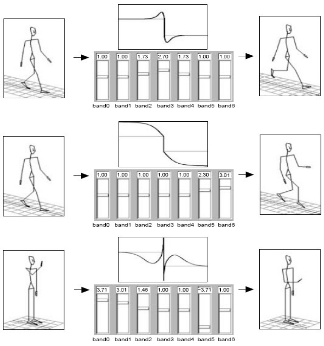
Motion Signal Processing [Bruderlin95]

Siggraph95



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Motion Signal Processing [Bruderlin95]

- Edit white values and red values with slider (multiplication)

Original Signal: 10 | 14 | 16 | 20 | 22 | 24 | 28 | 22 | … | …

Reconstructed Signal after editing: 7 | 11 | 19 | 23 | 20 | 22 | 23 | 29 | … | …

9 (± 2) | 21 (± 2) | 21 (± 1) | 26 (± 3) | …

15 (± 3x2=6) | 24 (± 1x2=2) | … x2

…

19.5 (± 4.5)

G = white values; L=red values

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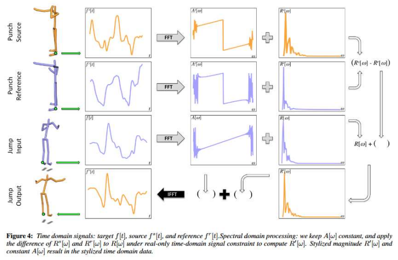
Signal processing and style [YM2016]

- Yumer M.E. and Mitra N.J., Spectral Style Transfer for Human Motion btw. Independent Actions, SIGGRAPH 2016.



VIDEO

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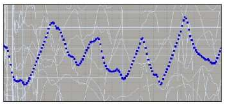
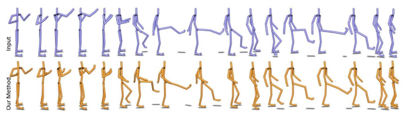


MOTION EDITING

Motion Blending between 2 Animations



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Motion Blending (interpolation)

- “Add” two motions together
  - Really interpolate
- m(t) = a m0(t) + (1-a) m1(t)
  - Note: this is a per-frame operation
- It works only if poses are similar!!!
- Very useful!
  - Often get small pieces of motion
  - Need to connect
  - Easy if motions are similar

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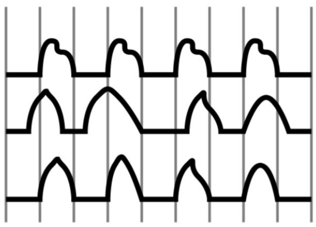
Motion Blending

- “Add” or "blend" two motions together
  - Works only if motion are synchronized



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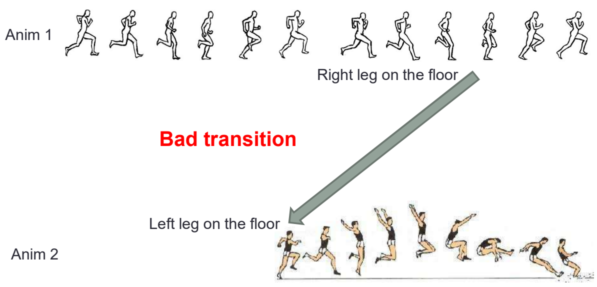
Motion Blending



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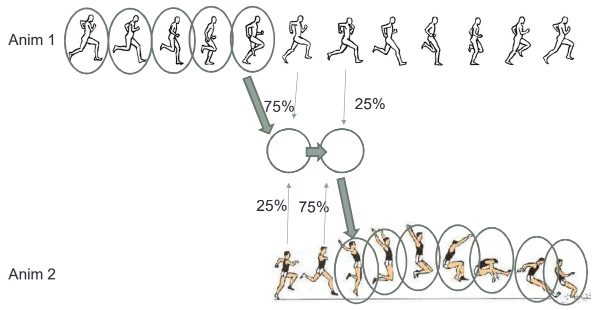
Motion Blending : good transition



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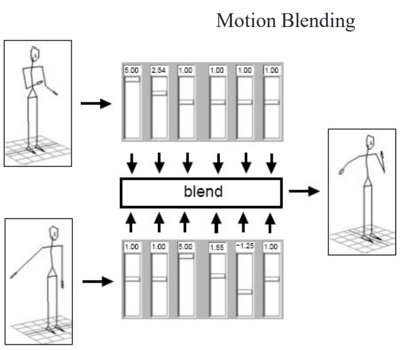
Motion Blending using Signal Processing

[Bruderlin95]

Siggraph95



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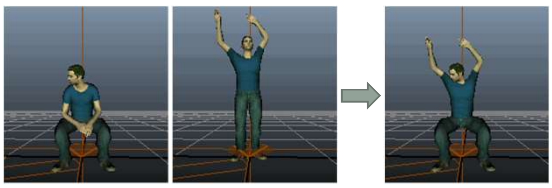
Motion Blend by Body Parts

- Combine different motions for each body parts



http://golaem.com

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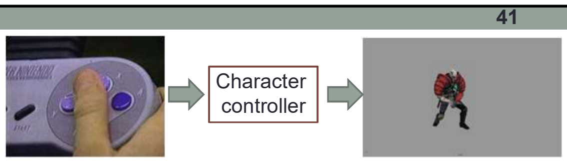

MOTION EDITING

Motion Blending between 2 Animations

➔Character Control

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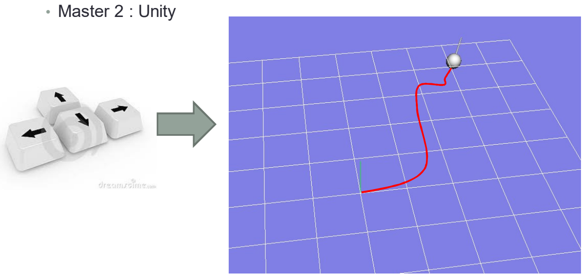
Character Controller (TP)

- First step: pilot a sphere/capsule
  - Master 1 : C++
  - Master 2 : Unity

DEMO



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Character Controller (TP)

```
class CharacterController
{
public:
        ... constructeur, set et get

        void update(const float dt);
        void turn(const Transform& transf_v);
        void turnXZ(const float& rot_angle_v);
        void accelerate(const float& speed_inc);
protected:
        Transform m_ch2w;   // matrice du character vers le monde
                            // le personnage se déplace vers X
                            // il tourne autour de Y
                            // Z est sa direction droite
        float m_v;      // le vecteur vitesse est m_v * m_ch2w * Vector(1,0,0)
        float m_vMax;      // ne peut pas accélérer plus que m_vMax
};
```

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Finite State Machines

- States represent animations
- Transitions represent instantaneous events
- Transitions can be triggered by
  - End of animation
  - Button press
  - In-game event (collision…)
  - Timers
  - Whatever…
- State machines can be blended. Blenders can be controlled by state machines…

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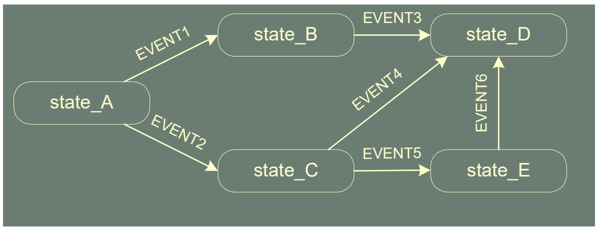
State Machines



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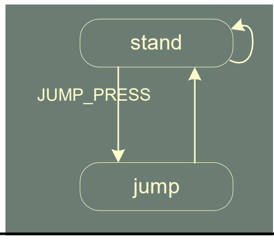
Simple Jump State Machine

- Consider a simple state machine where a character jumps upon receiving a JUMP_PRESS message



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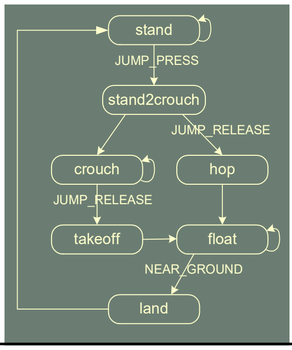
More Complex Jump



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State Machine (Text Version)

STATE	**EVENT**	**ACTION**
stand	{JUMP_PRESS	stand2crouch }
stand2crouch {		
	JUMP_RELEASE	hop
	END	crouch }
crouch	{JUMP_RELEASE	takeoff }
takeoff	{END	float }
hop	{END	float }
float	{NEAR_GROUND	land }
land	{END	stand }

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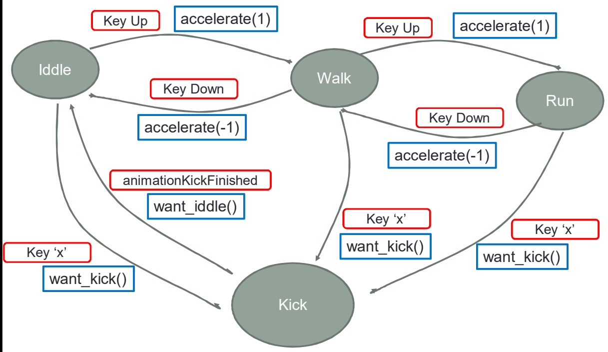
State Machine (example)



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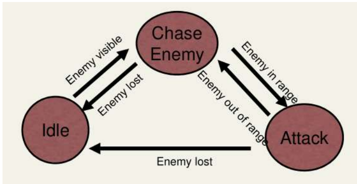
State Machines and IA

- FSM ➔ Behaviour ➔ Play Motion Capture Animation

IA Computer Animation

- First person shooter example



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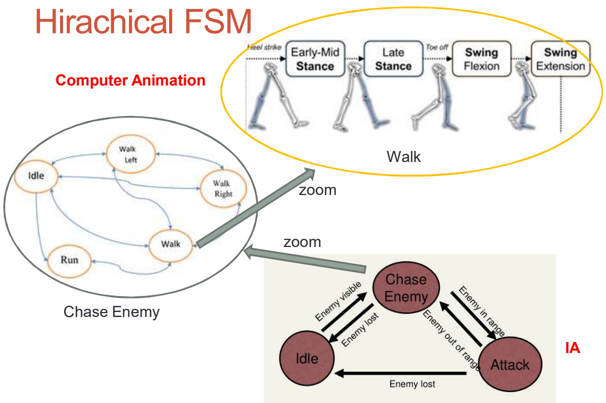
Hirachical FSM



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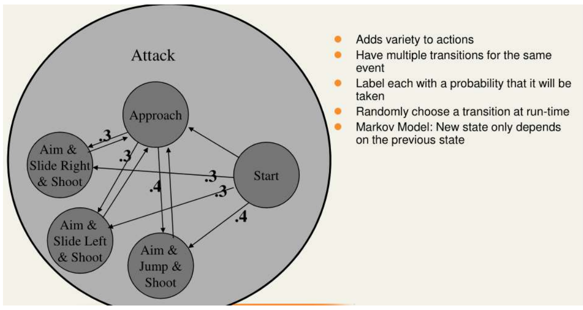
Non Deterministic Hierarchical FSM



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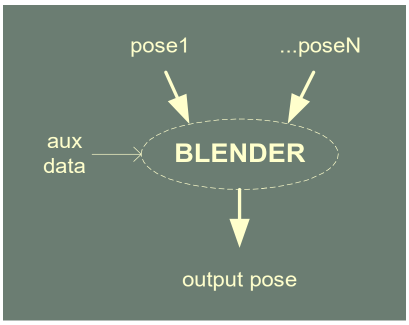
Need Generic Blend Operation



Cf. Quaternion + interpolation

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Advantage of FSM ☺

- Very fast – one array access
- Expressive enough for simple behaviors or characters that are intended to be "dumb"
- Can be compiled into compact data structure
  - Dynamic memory: current state
  - Static memory: state diagram – array implementation
- Can create tools so non-programmer can build behavior
- Non-deterministic FSM can make behavior unpredictable

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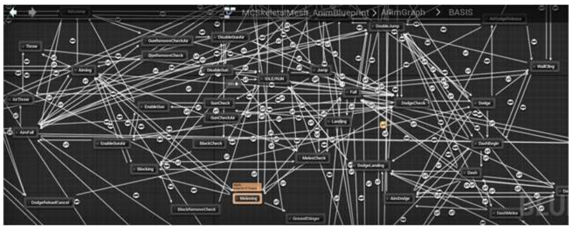
Spaghetti State Machines ☹



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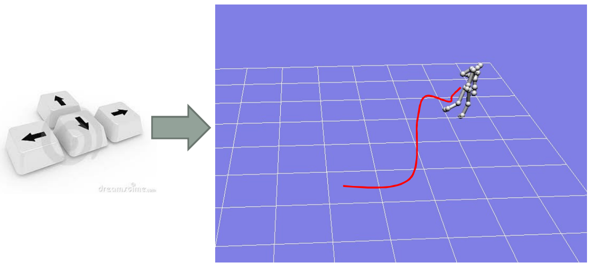
Character Controller (TP)

DEMO

Step 2: control the character with 3 animations + turn



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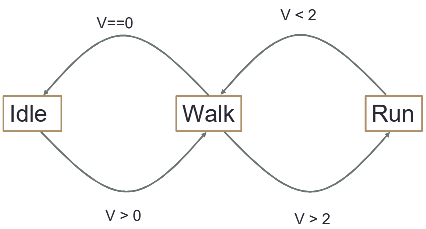
Finite State Machines (TP)



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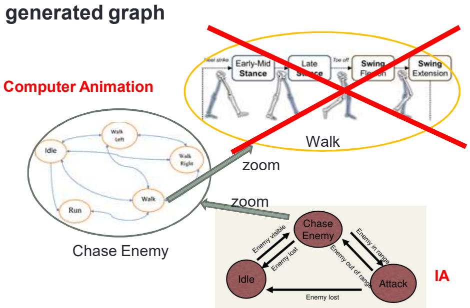
Motion Graph [Kovar, Gleicher, Pighin '02]

Replace FSM for animation part by an automatically generated graph



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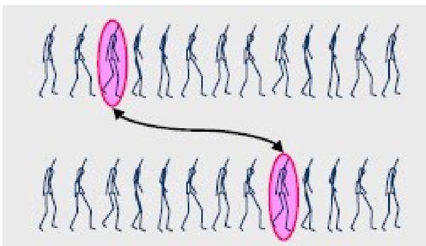
Idea: Motion Graph

Find Automatically Matching States in Motions



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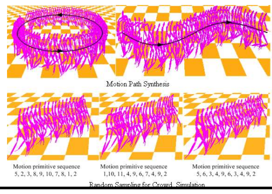
Idea: Put Clips Together

- New motions from pieces of old ones!
- Good news:
  - Keeps the qualities of the original (with care)
  - Can create long and novel "streams" (keep putting clips together)
- Challenges:
  - How to decide what clips to connect?
  - How to connect clips?



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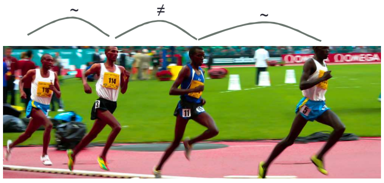
Connecting Clips: Transition Generation

- Transitions between motions can be hard
- Motion interpolation works *sometimes*
  - Blends between aligned motions
  - Cleanup footskate artifacts
- Just need to know when is “sometime”
  - Need a distance between pose



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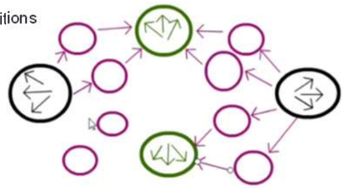
What are motion graphs?

- Directed graph representing a roadmap of motion data for a character
  - Vertex represent a pose in a motion clip
    - Vertex=(motion clip name, pose number)
  - Edges are pose transitions



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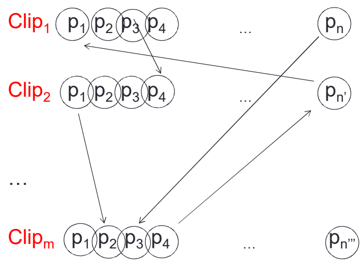
A simple motion graph



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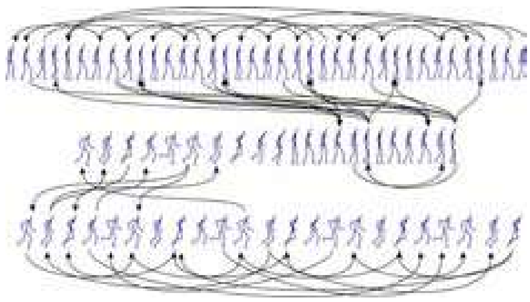
A simple motion graph



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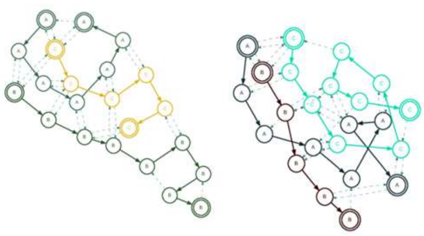
A simple motion graph

- Motion Blend & Motion Graph
  - Motion Graph more examples



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Building motion graphs

- Identify transition candidates
- Select transition points
- Eliminate problematic edges

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Identify transition candidates: pose distance

- For each pose A of clip C_j, calculate its distance to each other pose B of all other clip by basically measuring volume displacement

1) Initial frames we want to compare

2) Extract windows: frame before and after

3) Convert to point clouds

4) Align point clouds and sum squared distances

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Identify transition candidates: pose distance

- For each frame/pose A, calculate its distance to each other frame/pose B by basically measuring volume displacement
- Use a weighted point cloud formed over a window of k frames ahead of A and behind B, ideally from the character mesh $\min_{\theta,x_0,z_0} \sum_i w_i \|\mathbf{p}_i - \mathbf{T}_{\theta,x_0,z_0}\mathbf{p}'_i\|^2$
- Calculate the minimal weighted sum of squared distances between corresponding points, given that a rigid 2D transformation may be applied to the second point cloud

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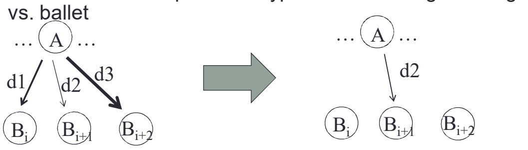
Select transition/edge

- The previous step gave us all the local minima of the distance function for each pair of points
- Now we simply define a threshold and cut transition candidates with errors above it
- May be done with or without intervention
- Threshold level depends on type of motion – eg. walking vs. ballet



We define transition only between pose with significant similitude

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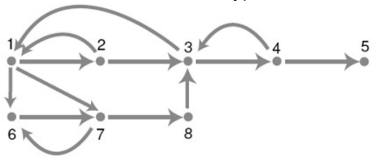
Eliminate problematic edges

- We want to get rid of:
  - Dead ends – not part of a cycle
  - Sinks – part of one or more cycles but only able to reach a small fraction of the nodes
  - Logical discontinuities – eg. boxing motion forced to transition into ballet motion
- Goal is to be able to generate arbitrarily long streams of motion of the same type



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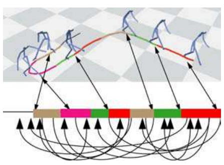
Using a motion graph

- Any walk on the graph is a valid motion
  - Generate walks to meet goals
  - Random walks (screen savers)
  - Search to meet constraints
- Other Motion Graph- like projects elsewhere
  - Differ in details, and attention to detail



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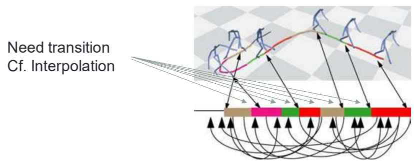
Transitions

- When need to make the transition between frames A_i and B_j blend Ai through A_{i+k-1} with Bj through B_{j-k+1}
  - Align frames with appropriate rigid 2D transformation
  - Use linear interpolation to blend root positions
  - Use spherical linear interpolation to blend joint rotations



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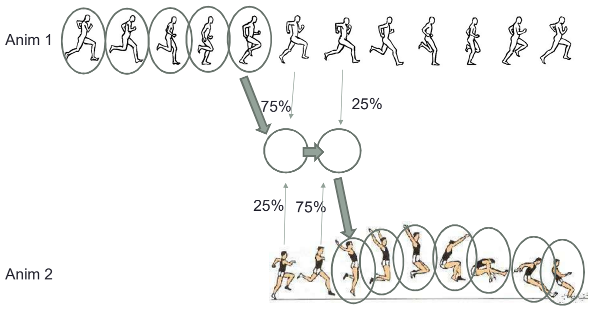
Motion Blending : good transition



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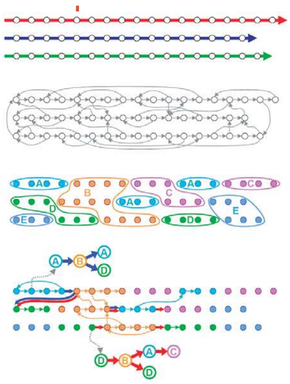
Clustering a motion

- Clustering the graph
  - For a big graph
  - →Build a meta-graph
  - Improve the exploration



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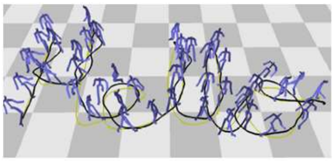
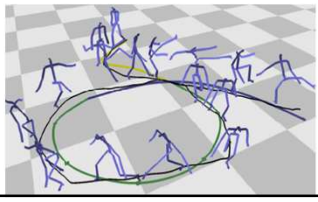
Results



+ video



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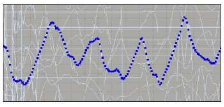
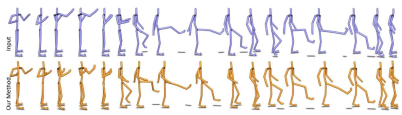


MOTION EDITING

Motion Blending between N Animations



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Motion blending

- Often 2 animations not enough to produce realistic moves
- For instance N animations : turn left with different angles
- Interpolating 3 or more angles
  - angle = w_0 x $angle_0$ + w_1 x $angle_1$ + w_2 x $angle_2$
  - avec $\sum w_i=1$
  - Animations need to be synchronized
- Problem: how to find the weight w_i
  - Inverse distance weighting (See Unity)
  - Barycentric
  - KNN
  - RBF

+VIDEO

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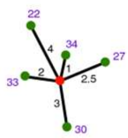
Motion blending : barycentric

- Inverse distance weighting
  - w_i = 1/distance
  - Normalization of weights
  - Simple computing
- You have to define the position of the animations clips



$$Z(x) = \frac{\sum w_i z_i}{\sum w_i} = \frac{\frac{34}{1^2}+\frac{33}{2^2}+\frac{27}{2.5^2}+\frac{30}{3^2}+\frac{22}{4^2}}{\frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{2.5^2}+\frac{1}{3^2}+\frac{1}{4^2}} = 32.38$$

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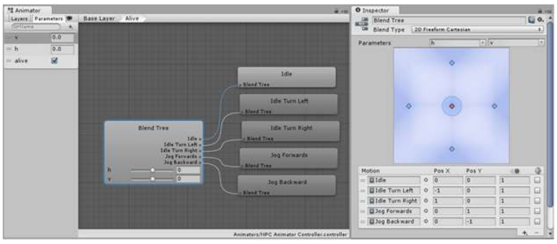
Unity : Blend Tree

- Unity : blend tree
  - Finite State Machine
  - Motion blending with inverse distance weighting



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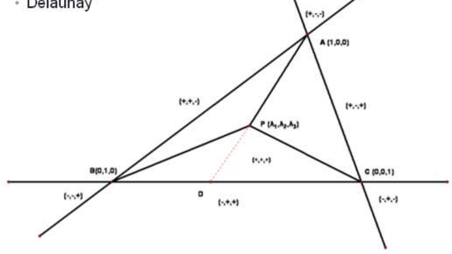
Motion blending : Barycentric Int

- Barycentric Interpolation
  - Need to « triangulate » the positions of the animations
    - Delaunay



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Motion blending : RBF

- RBF : Radial Basis Function

$$y(\mathbf{x}) = \sum_{i=1}^{N} w_i \, \phi(\|\mathbf{x} - \mathbf{x}_i\|),$$

- Sum of N radial basis functions, each associated with a different center x_i
- Weight w_i are computed with linear least square method

- Gaussian:

$$\phi(r) = e^{-(\varepsilon r)^2}$$

- Multiquadric:

$$\phi(r) = \sqrt{1 + (\varepsilon r)^2}$$

- Inverse quadratic:

$$\phi(r) = \frac{1}{1 + (\varepsilon r)^2}$$

- Inverse multiquadric:

$$\phi(r) = \frac{1}{\sqrt{1 + (\varepsilon r)^2}}$$

- Polyharmonic spline:

$$\phi(r) = r^k, \qquad k = 1, 3, 5, \dots$$
$$\phi(r) = r^k \ln(r), \qquad k = 2, 4, 6, \dots$$

- Thin plate spline (a special polyharmonic spline):

$$\phi(r) = r^2 \ln(r)$$

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Motion Field

- To got further from the interpolation techniques
  - Animation are set on space automatically by a k-nearest neighbor

$$d(m, m') = \sqrt{\begin{array}{rr} \beta_{\mathrm{root}} \|v_{\mathrm{root}} - v'_{\mathrm{root}}\|^2 & + \\ \beta_0 \|q_0(\hat{u}) - q'_0(\hat{u})\|^2 & + \\ \sum_{i=1}^{n} \beta_i \|p_i(\hat{u}) - p'_i(\hat{u})\|^2 & + \\ \sum_{i=1}^{n} \beta_i \|(q_i p_i)(\hat{u}) - (q'_i p'_i)(\hat{u})\|^2 & + \end{array}}$$

- Reinforcement Learning to produce the desired animation
  - States
  - Actions
  - Transition
  - Reward

+VIDEO

Motion Fields for Interactive Character Animation
Lee etal SIGGRAPH 2010

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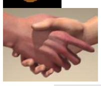
Conclusion

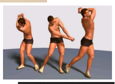
Data-driven approach for

- Facial animation

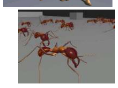
- Hand animation



- Skin deformation



- Animal animation



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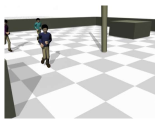
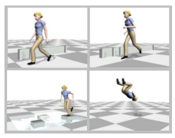
Conclusion

Combine mocap data with other techniques

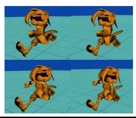
- Motion planning



- Physically based animation



- Key-framing



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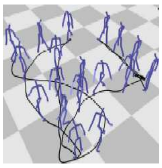
Conclusion

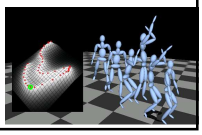
Data-driven motion synthesis

- Motion graphs/patches



- Motion interpolation

- Statistical motion synthesis



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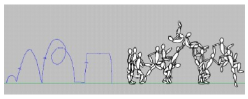
Conclusion

Animation control

- Online animation control

- Offline Animation control



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