Editing and Retargetting Animated Motion with Spacetime Constraints

Michael Gleicher
Autodesk
Mountain View, CA
gleicher@cs.cmu.edu
http://www.gleicher.com/mike

The Dream:
Animation for the rest of us!

- Animation and Special Effects are talent and labor intensive
- Can we make it easier?
  - available to casual users?
  - less labor for pros?
- Projects towards this goal:
  - Motion Adaptation
  - Motion from Performance
  - Video Tracking

Motion Adaptation

- Motion is hard to create
- Easier to borrow, steal, buy, ...
  - Goal: libraries of clip motion
- Most motion is not reusable
  - particular character, action, context...
- Adapt/edit/adjust to be something else?

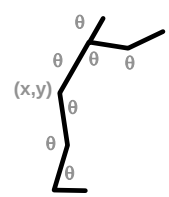
> Given: Good motion, new needs
> Find: New motion
> meets new needs
> preserves original quality

What do we mean by motion?

- Animated Character
- Pose or Configuration
  - parameters in a vector

$$\mathbf{p} \in \Re^n$$

- Examples are articulated figures (humans)
  - trees of rigid links
  - center + joint angles
  - nothing specific about methods



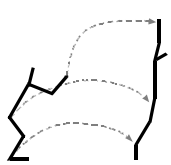
$p = \{x, y, \theta_1, \theta_2, \theta_3, \ldots\}$

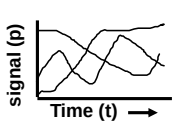
What do we mean by motion? (2)

- A motion maps times to configurations

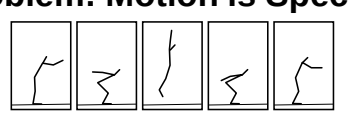
$$\mathbf{m}(t) \in \Re \Rightarrow \Re^n$$

- Vector-valued, time-varying signal
- Representation comes from creation
  - typically interpolation
  - may not be convenient for editing





Problem: Motion is Specific

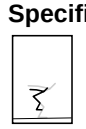


Specific Action

hand is not here

Edit **motion to meet new needs**

Specific Character



different sized character doesn't fit

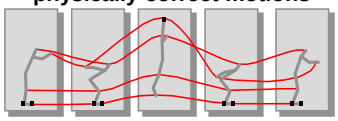
Retarget **motion to new character**

Previous Techniques

- Generate new motions
  - may lose what we had
- Manually tweak each frame
  - lots of work
  - may not preserve original
- Signal processing
  - works for certain types of alterations
  - may not preserve constraints

Spacetime Constraints

Previously: a method for synthesis of physically correct motions



- Consider all constraints simultaneously
  - NOT frame at a time
- Solve for motions
  - "best" motion that meets constraints
- Physics is just a constraint

Solution: Adaptation by Spacetime Constraints

- Define geometric constraints on frames of the motion
  - properties to preserve
  - new goals to establish
- Find new motions that:
  - satisfy constraints
  - match original motion
- Spacetime constraints consider entire motion simultaneously

Spacetime Constraints for Motion Adaptation

Motion Editing with Spacetime Constraints
- provide direct manipulation editing
- adjust constraints over motion
- emphasize solution speed over quality

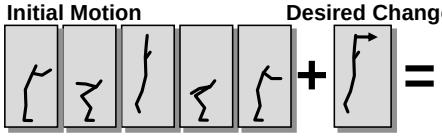
Retargetting Motion to New Characters
- apply motion to differently sized character
- find adaptation to re-establish constraints
- avoid uncharacteristic adaptations

Motion Editing with Spacetime Constraints

- A model for motion editing
  - Constraints over whole motion
  - User adjusts and adds constraints
- Solve for new motions
  - satisfy constraints, preserve motion
  - emphasize fast solutions for interactivity
  - bad solution? user adds more constraints!
- User interface issues
  - Must visualize motion and changes
  - Must specify and edit constraints

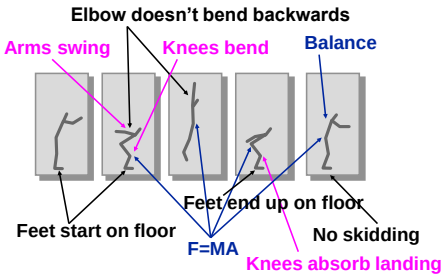
An Editing Example

Initial Motion Desired Change

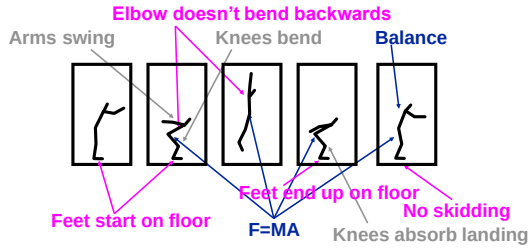


- What is a good answer?
  - Character meets new goal
  - Preserves original
  - Resulting motion is a jump
- Hard to define in general

What makes a jump a jump?



What makes a jump a jump?



Geometric Constraints - implement as constraints
Signal Characteristics - get from signal matching
Other Constraints - could be added later

Mathematically...

- **Configuration:** $\mathbf{p} \in \Re^n$
- **Motion:** $\mathbf{m}(t) \in \Re \Rightarrow \Re^n$
- **Initial Motion:** $\mathbf{m}_0(t)$
- **Constraint:** $f(\mathbf{m}(t)) = c$
  $f(\mathbf{m}(t)) \geq c$
- **Variational Constraint:** $\forall_{t \in t_1 \ldots t_2} f(\mathbf{m}(t)) = c$
  $\forall_{t \in t_1 \ldots t_2} f(\mathbf{m}(t)) \geq c$

The Problem

- Find $\mathbf{m}(t)$ such that
  - the constraints are satisfied $f(\mathbf{m}(t))=c$
  - an objective function $g(\mathbf{m}(t))$ is minimized
- A variational, constrained, optimization

The Questions

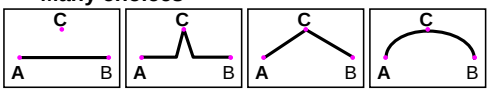
- What f (constraints)?
- What g (objective)?
- What representation for $\mathbf{m}(t)$?
- How to solve it?
- How to present it to the user?

Constraints

- Describe features of motion
  - limitations on character
  - essential constraints on motion
  - future: physics, form, ...
- Palette of controls for user
- Nonlinear functions, inequalities
- Implement variational by sampling

The Objective

- Measure difference between m(t) and $m_0(t)$
- Many choices



Match Value Velocity Acceleration

- No obvious, general right answer
  - results are non-intuitive
  - choice effects solution difficulty
  - off-load importance with constraints

Strategies (project phases)

1. Do something simple (show it works)
2. ~~Find useful objectives, present to user~~
3. Make it go fast

Why speed over correctness?
- What is "correct" anyway?
- Good objectives too hard to solve
- Constraints preserve important features
- **Interactivity!**

Solving Non-Linear, Constrained Optimization Problems (a very brief primer)

- **There is no guaranteedWell established, centuries old heuristics...**
- **Iteratively refine a solution**
  - **each step moves closer (hopefully)**
- **Solve series of approximate problems**
  - **choose solvable sub-problems**
  - **linear systems, quadratic optimization**
- **Sequential Quadratic Programming**

How to make it fast

- **Get a fast computer**
- **Do good computer science (algorithms/caching/...)**
- **Exploit sparsity**
- **Precision isn't important**
  (trade everything for speed)
- **Differentialness**
- **Constrain the search space**

Motion Displacement Mapping

- **Define** $\mathbf{m}(t)=\mathbf{m}_0(t)+\mathbf{d}(t)$
- **Search for** $\mathbf{d}(t)$

- **Advantage: representation independence**
  - **pick representation for displacement based on desired changes, ease of solution**
- **Use B-Spline displacement curves**

The Numerical Problem

x = concatenation of B-Spline controls

d(t) = $\mathcal{B}$**(t,x)**

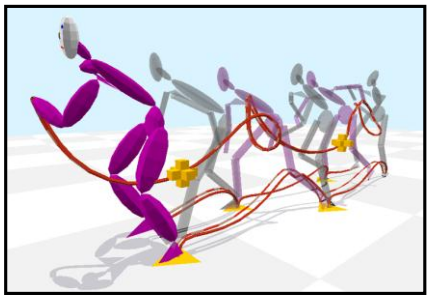
g(x) = 1/2 xMx (**M** is a diagonal matrix)

f(x) = c(k(m0(t)+$\mathcal{B}$**(t,x)))**

k = character's kinematics

c = constraint function

Feedback

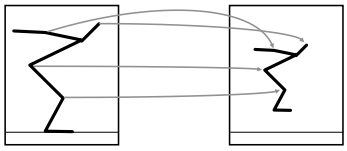


What to look for in the video

- All in real time on a Macintosh
- All interaction is direct manipulation
- Up to 5400 constraints (final example)
  - at most a handful are specified by user
- Various display mechanisms
  - cycling, strobing, stream lines, ...
- Initial solutions OK, but usually adjusted

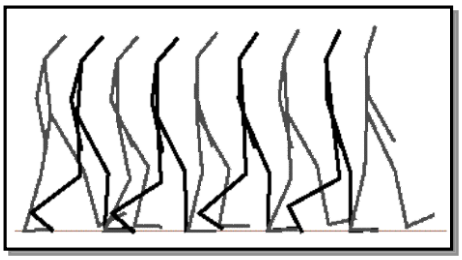
Retargetting Motion to New Characters

- Consider characters with identical structure, but different limb lengths

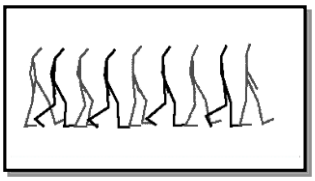


•Parameters can be re-applied
•But some things are different

What makes *this* walk *this* walk?



Hint:
It may not be invariant to the size of the character...



Adaptation of the motion makes it more like original (by the important metrics)

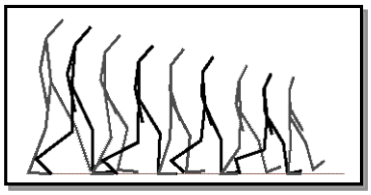
Ideally:

- Define motion concepts mathematically
  - smooth, physical, realistic, walking
  - depressed, energetic, drunken
  - with proper ballet form
  - like Gene Kelley in *Singing in the Rain*
  - ...
- Determine which are appropriate
  - and which the user cares about
- And employ these complex criteria in the spacetime formulation

Retargetting in Practice...

- Use constraints for specific geometric requirements that must be maintained
- Compute adaptations that re-establish geometric constraints
- Avoid "objectionable" adaptations
  - large magnitudes of change from original
  - frequency characteristics unlike original
- Find minimal, band-limited adaptation
  - select displacement map to enforce band limits

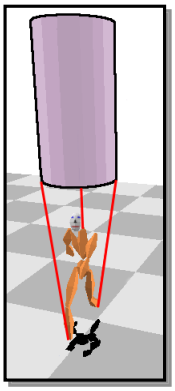
Motion for Morphing



- **Retarget motion to time-varying size**

Characters with Different Structure

- **Creativity vs. Automation**
- **User defines point correspondences**
- **Adapt similar structure to same size first**
- **Different numbers of degrees of freedom**
  - **least squares (too few)**
  - **objective (too many)**



What next?

Make animation easier to produce!

- **Where do we get motions from?**
  - motion capture, databases, synthesis, ...
- **What high-level properties to find?**
  - how to encode, specify, compute, ...
- **How to automate the process?**
  - constraint detection, property identification, ...
- **How to apply the results?**
  - skelletal motion is only half the battle
  - Automatic Anthropomorphism

Summary

- ***Spacetime Constraints* are used to adapt motions.** (not just physical synthesis)
- ***Motion Displacement Maps* provide representation independence.**
- **Concessions to pragmatism afford a realistic approach.** (and opportunities for future work)
- **Practical Solutions demonstrated on *real problems.***