# Motion Synthesis By Example

## Animating characters in games from data

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# Synopsis

Game characters are getting pretty good

- How are they doing it?

Synthesis-By-Example is the prevailing approach

- What is it? Why does everyone like it?

SBE Methods are build from some basic pieces

- How do they work? What are the building blocks?

Research uses these same building blocks

- Can research help real games?

# Where is this going?

Example video from Heck&Gleicher ‘07

# What did you just see?

- Interactively controllable character

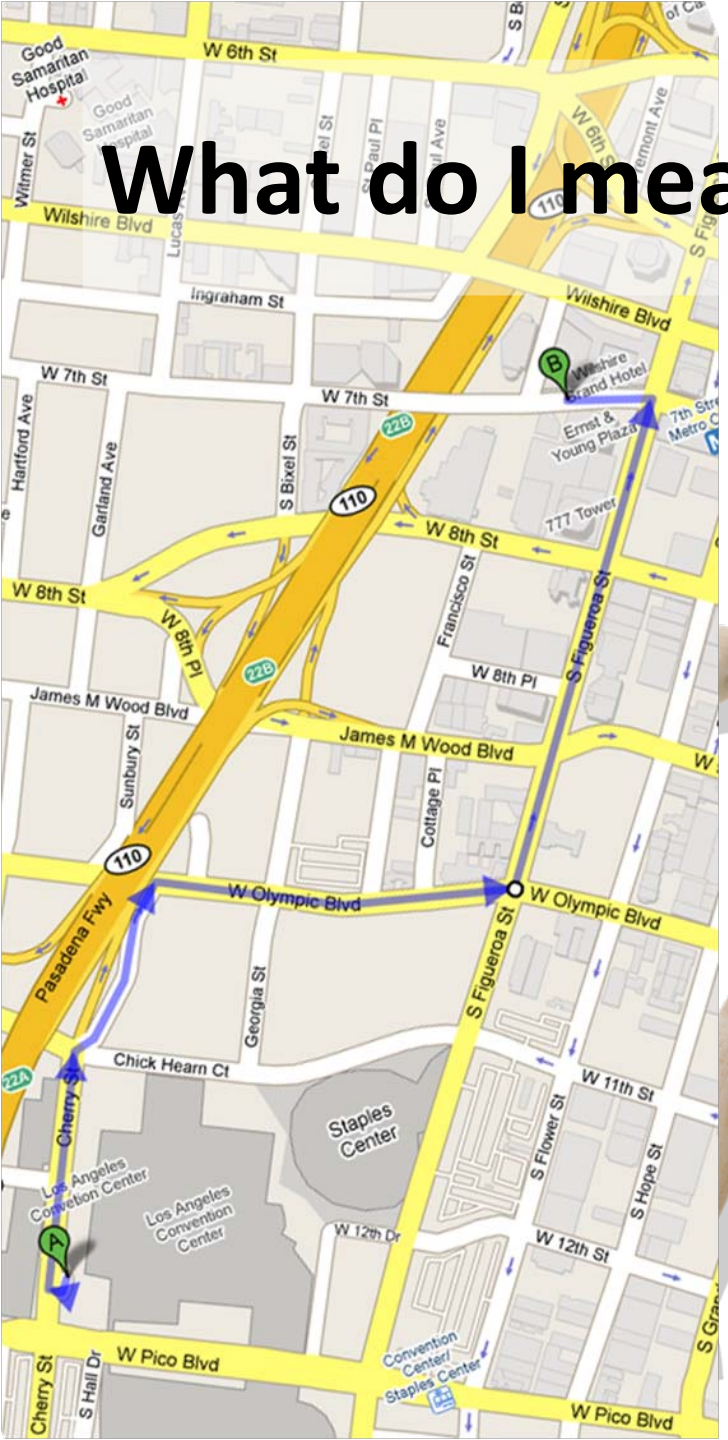
- Stream of high-quality motion
- Continuous control (not discrete choices)

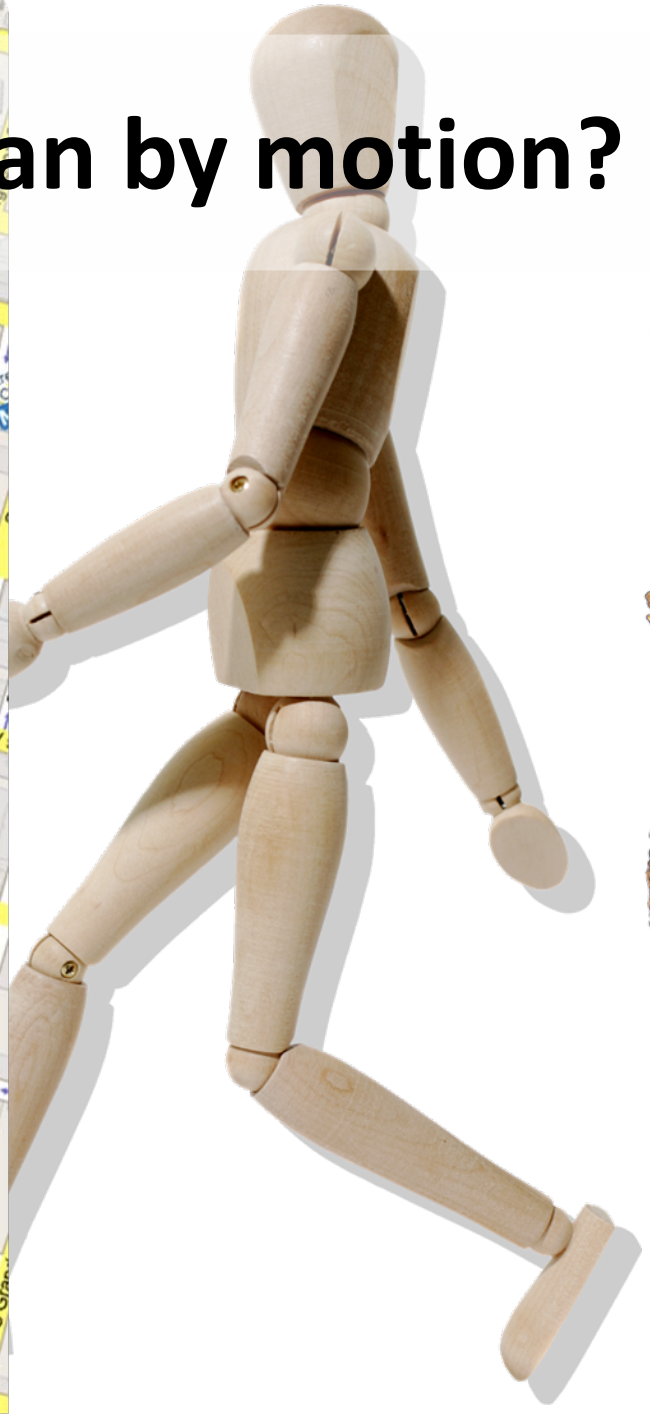
- How did it do it?
  - Dynamically assemble motions by putting together pre-recorded clips (lots of them)

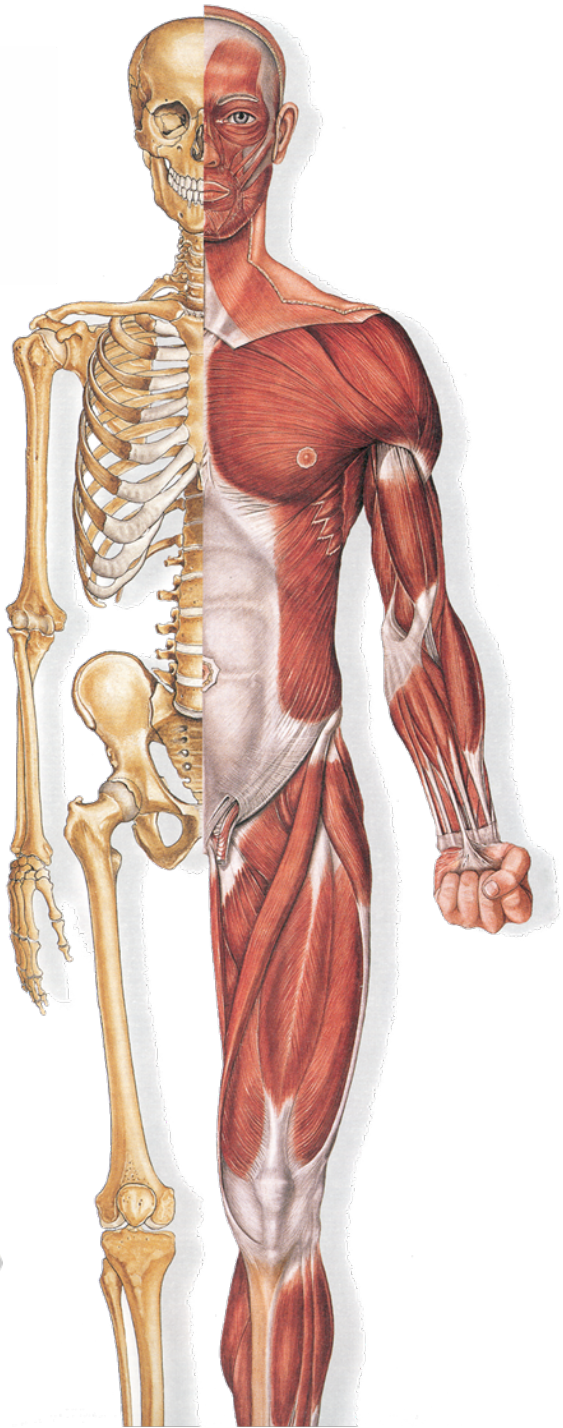
# Roadmap

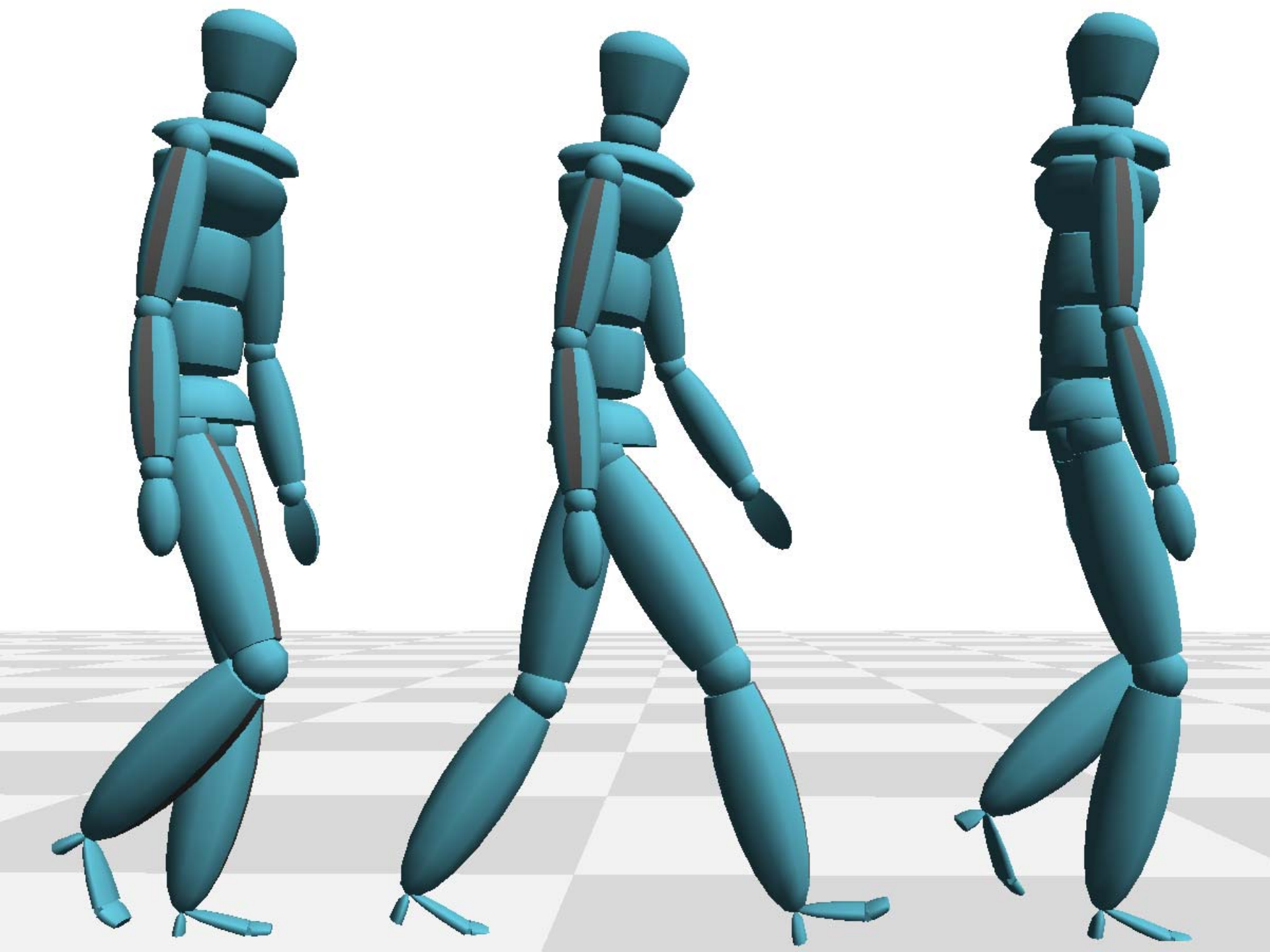
- Basics of Synthesis-By-Example (SBE)
  - Concatenation as an example
- SBE in Practice vs. Research
  - Blending-based parameterization as an example
- Creating controllable characters
  - Parametric graphs as an example

# What do I mean by motion?







# Game characters are getting pretty good



# Why are interactive characters hard?

Human Motion is:
- Complex
- Diverse
- Subtle

Expressive
(but express the right things)

Game Characters must be:
- Efficient
- Dynamically controlled
- Responsive
- Situated (-> precise)

Interactive

# Games characters are getting pretty good

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# Motion Capture
## (and other recorded motion)

Motion Capture has Matured

- High-End systems evolved
- Low-End systems emerging

Partnership:
Actor, Director, Technologist

Keyframed motion is similar

# Pre-Recorded Motions are Easy (ok, easier)

- Motion is a set of geometric measurements
  - Positions, angles over time

- Easy to use – just play it back
- Motion is just data
  - Artist / Performer gave us what we want
  - We don’t know what or why (or need to)

- Individual examples of one movement
- Doesn’t provide interactivity / controllability

How to make *interactive* characters?

# Two Approaches

**Model-Based / Algorithmic**

- Generate motions algorithmically
- Craft methods for motions

- Motion complexity handled by clever algorithms

- Develop models per motion
- Have a motion model
  - Generate more motion

**Synthesis-By-Example**

- Assemble new motions from example data
- Simple, generic algorithms

- Motion complexity comes from example data

- No per-motion models
- No motion model
  - Limited adaptability

# Example-Based Synthesis

***Capture*** the detail, subtlety and complexity

Good News:

We don’t need to model all the complex things!

Bad News:

We don’t have a model to generate what we didn’t capture!

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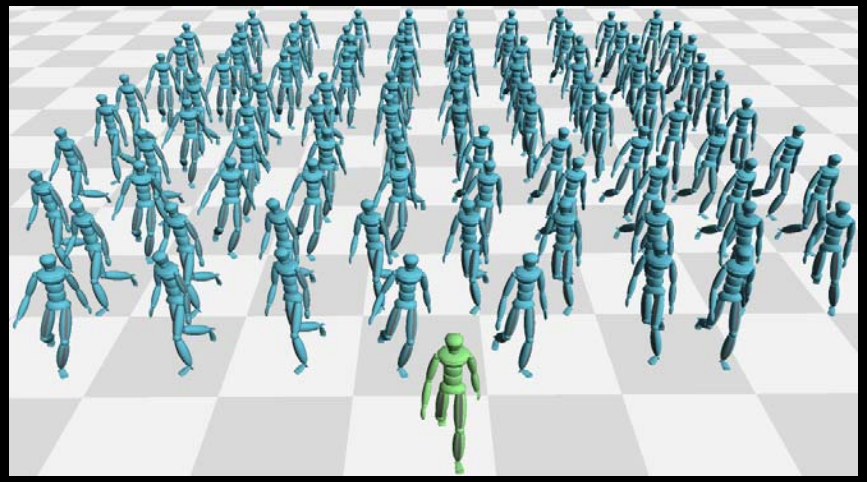
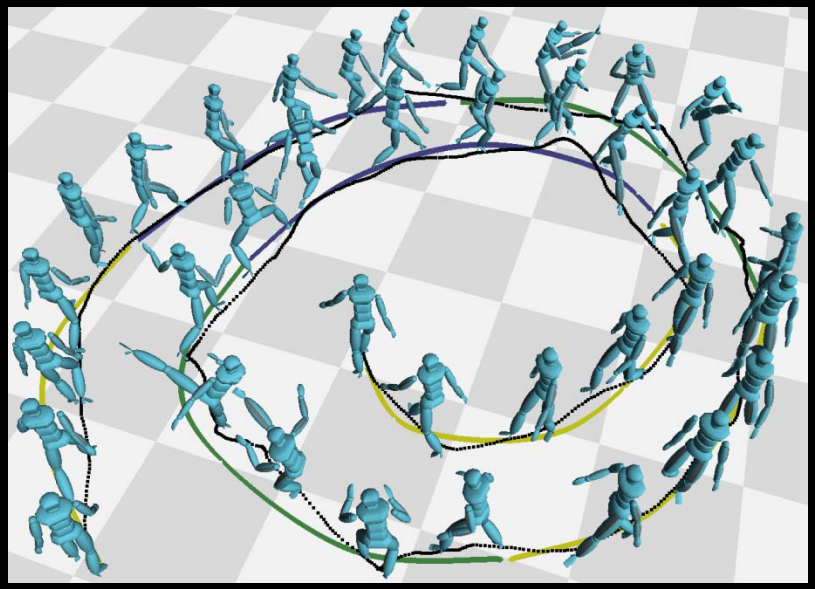
# Synthesis By Example

Create what you need from what you have



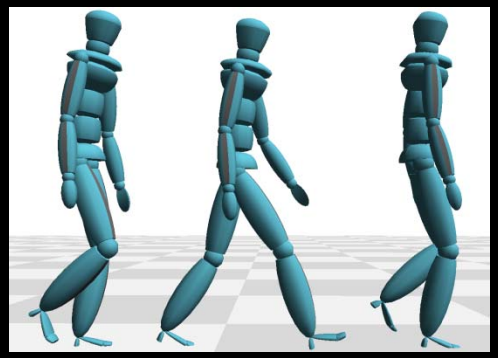


Have: Lots of Clips

Want: Long Streams
Want: Controllable
Want: Precise/Continuous

# Concatenation

Put clip after clip after clip …



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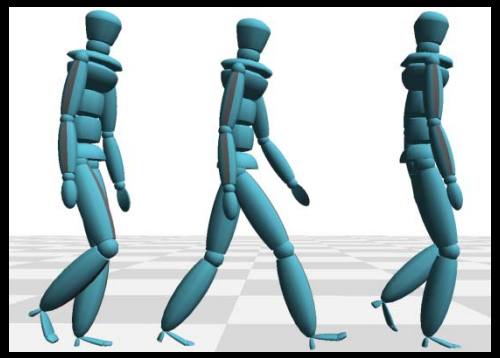

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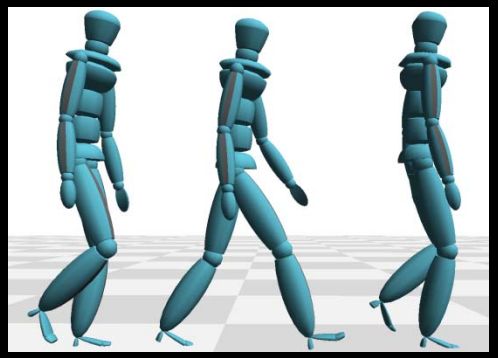
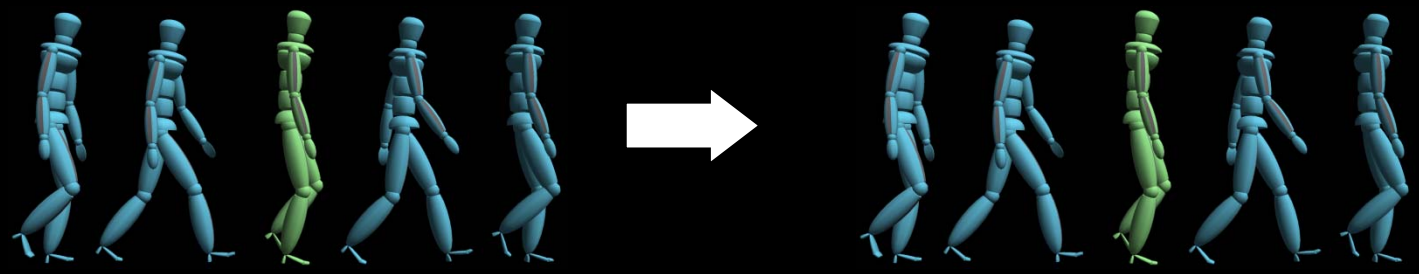
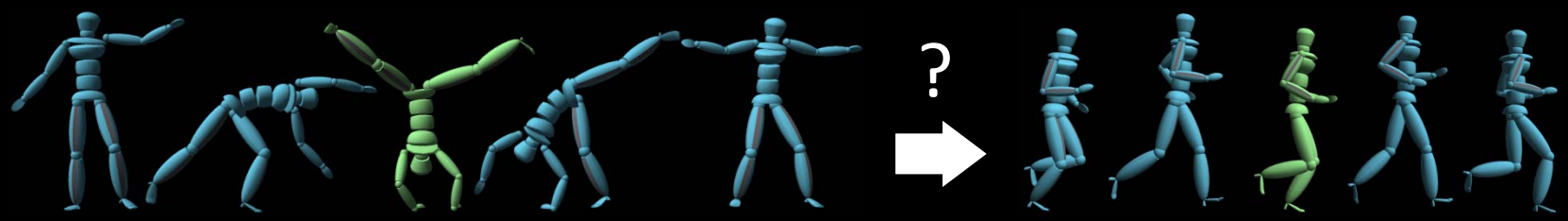


# Transitions

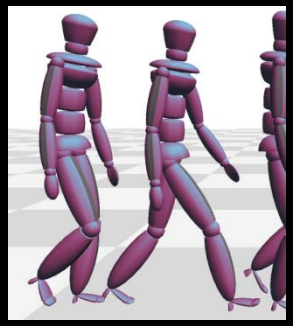
Some transitions are easy



Some transitions are hard



# Simple Transition Methods



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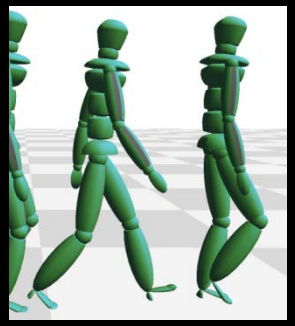
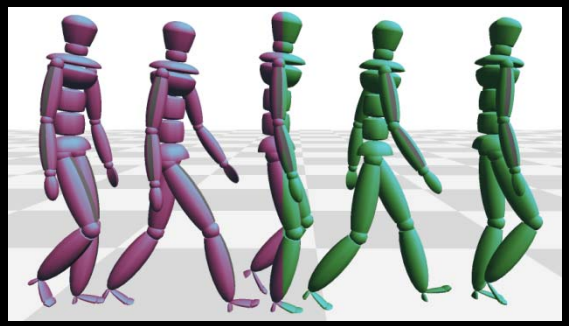
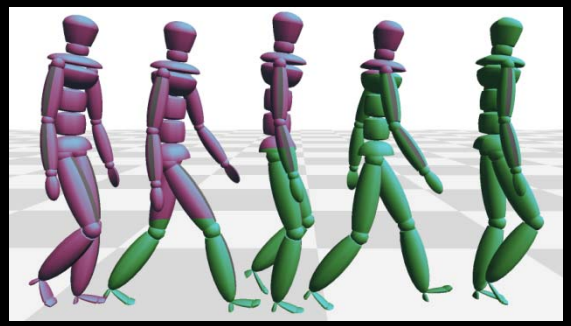




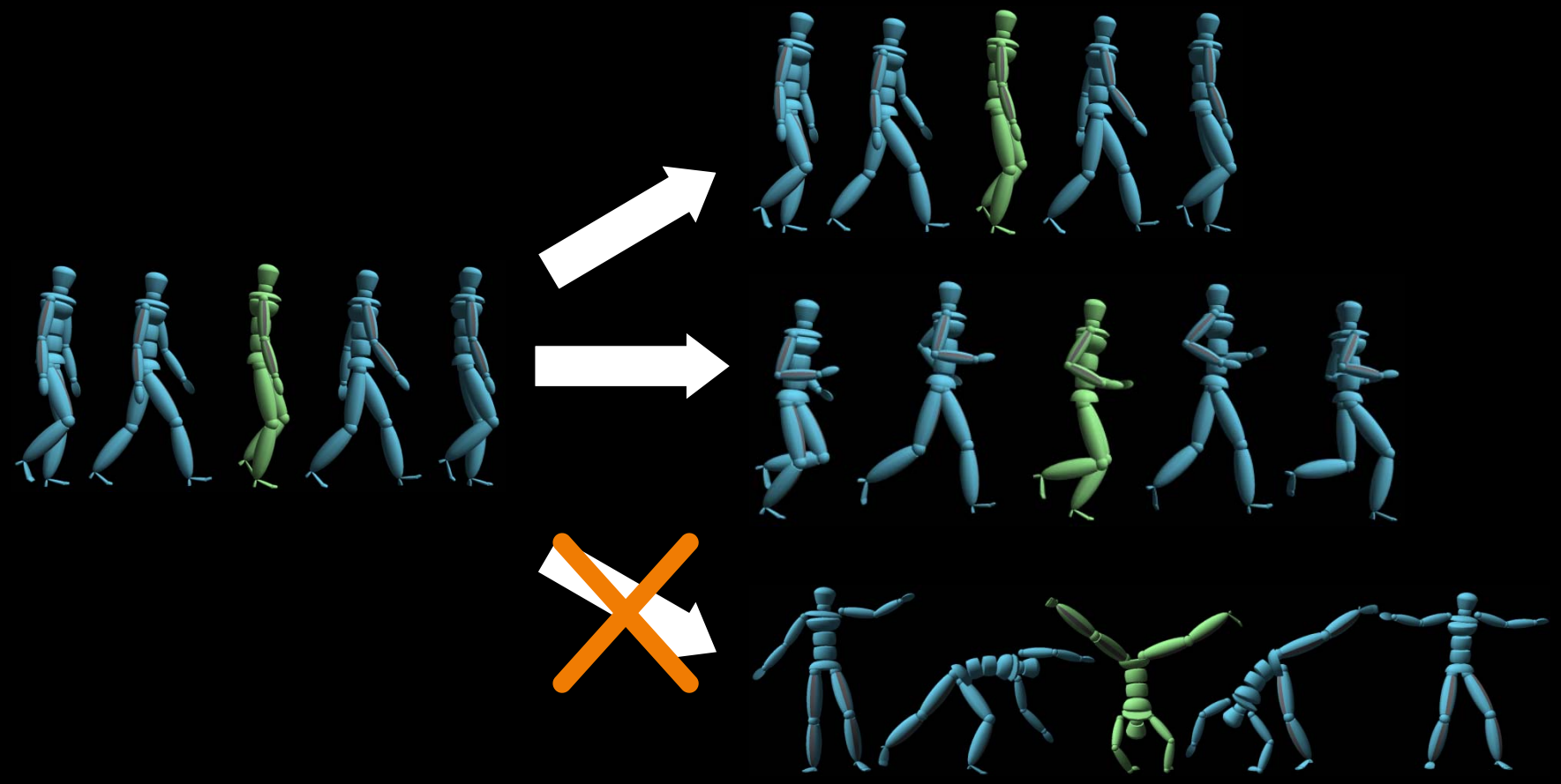
Cut transition



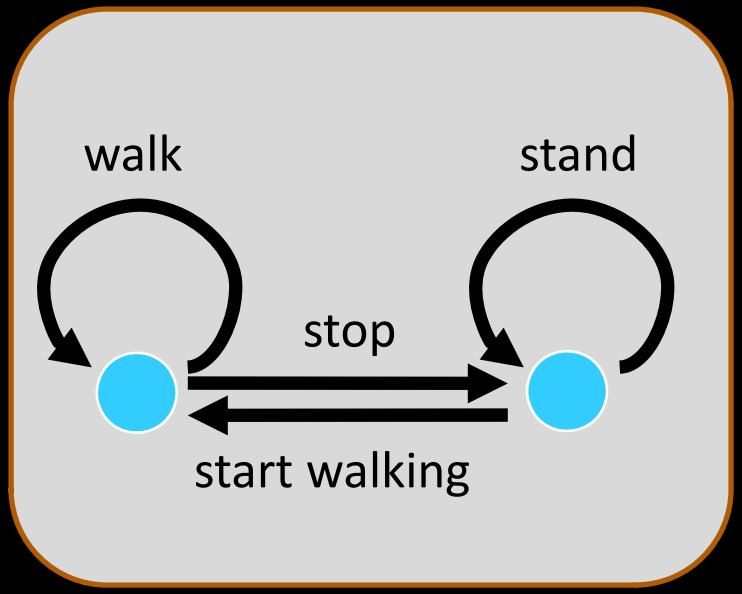
Blend Transition

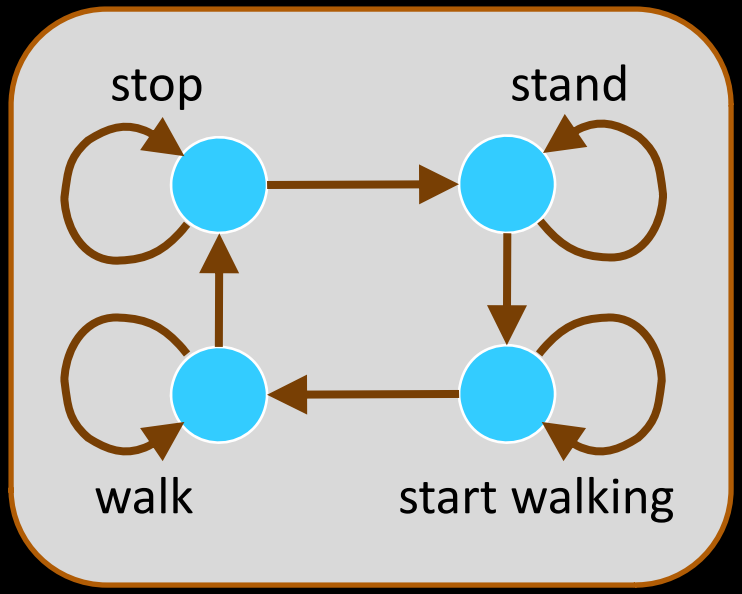
# Motion Graphs
# (aka Move Trees)

Some transitions are easy – remember which



# Graph Notation




Edge = clip

Node = choice point

**Graph walk = motion**

Edge = valid transition

Node = clip

**Graph walk = motion**

# Concatenation-Based Synthesis

Key Idea:

- Only create transitions where simple transitions are likely to work

Historically (in practice, particularly games)

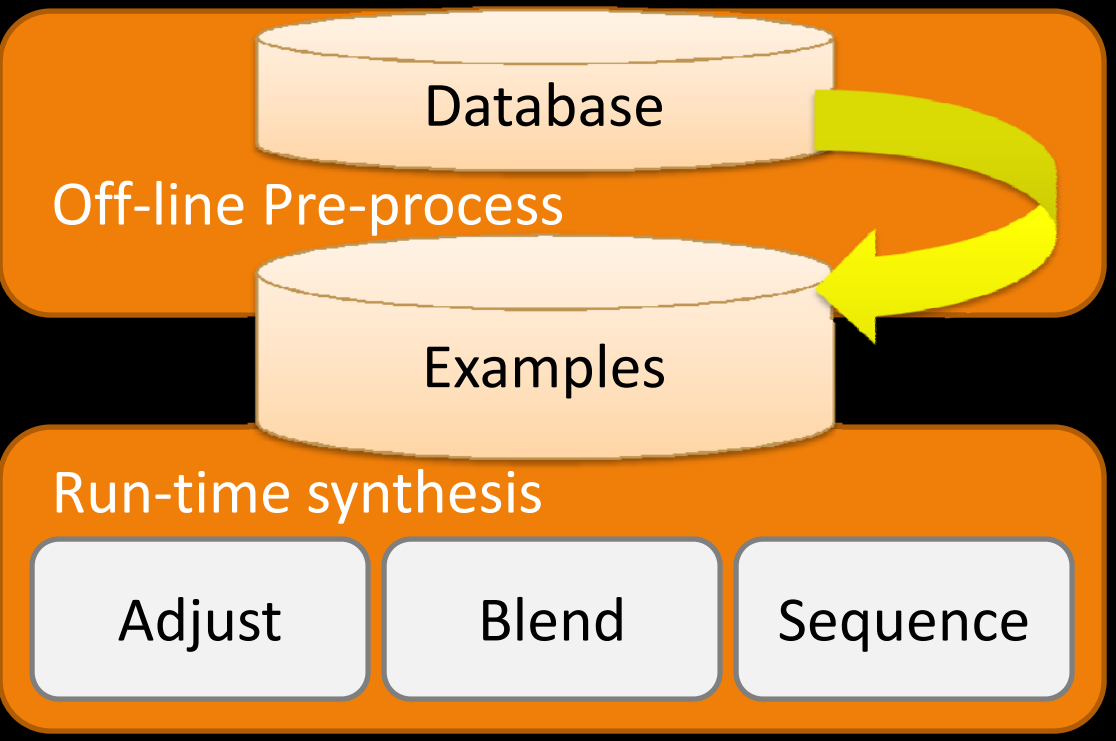
- Craft motions to have easy transitions

In Research (starting around 2002)

- Find metric to automatically determine what motions are “close” enough for transitions to apply

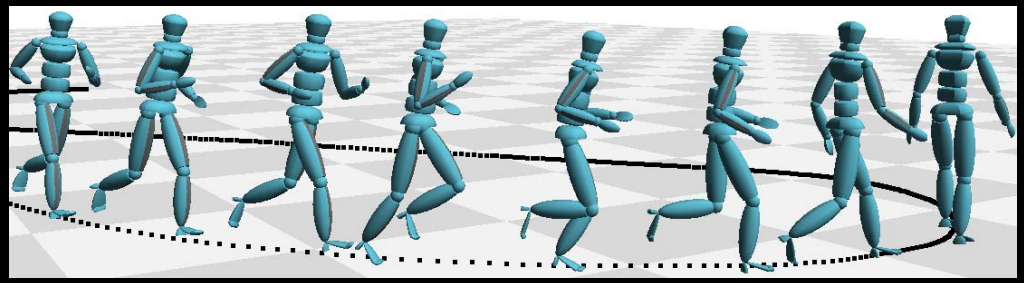
Kovar et al, Arikan&Forsyth, Lee et al. – All SIGGRAPH 02

# Basic Ideas of Synthesis-By-Example




**Preparation:**
Extract / process example from source data such that assembly methods work

**Assembly:**
At run time assemble examples using a few generic (simple) methods



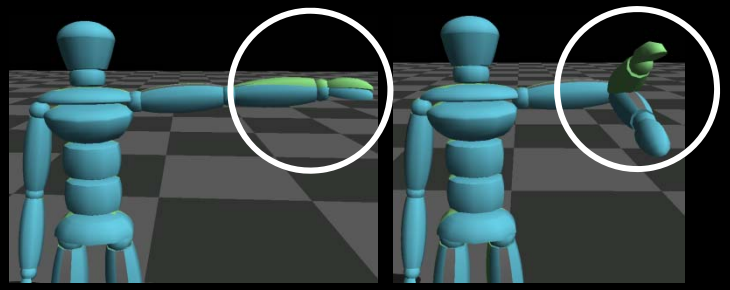
**Control:**
Choose what is assembled to meet needs (e.g. driven by user, meet goals, …)

# SBE in Practice vs. Research
## (practice has been doing it longer)

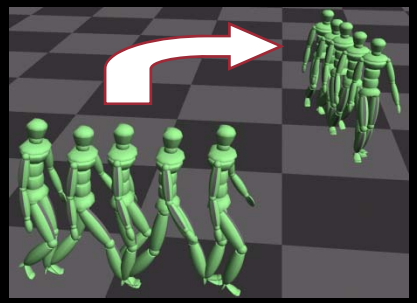
| | Practice (real games) | Research |
|---|---|---|
| **Preparation:** | Planning<br>Careful preparation<br>Manual adjustment | Automation<br>Automation<br>Automation |
| **Assembly:** | Basic methods<br>Tweaks thrown in | Basic methods<br>Tweaks thrown in |
| **Control:** | Carefully crafted&tuned<br>Structured data makes problem easier | Search<br>Pre-Processing<br>Control theory |

# Determining potential transitions

- Need to account for derivative continuity
- Joint angles are difficult to compare directly
  - Effect of perturbation (e.g., rotate shoulder) depends on pose



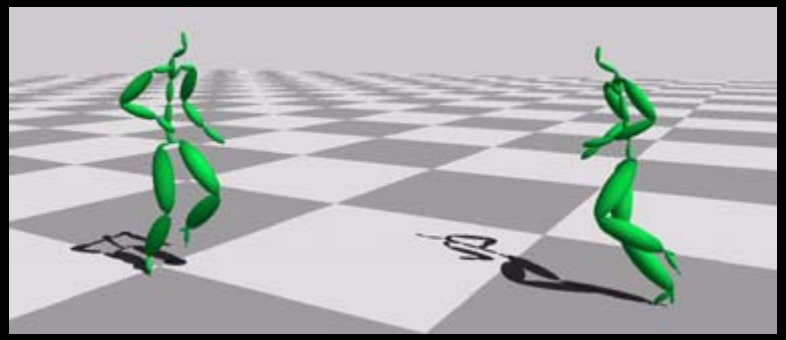
- Need coordinate invariance
  - Different camera ≠ different motion!



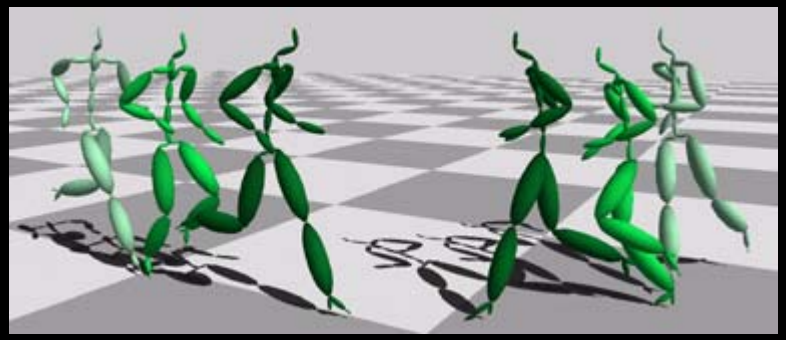
# What is Similar?

## Factor out invariances and measure

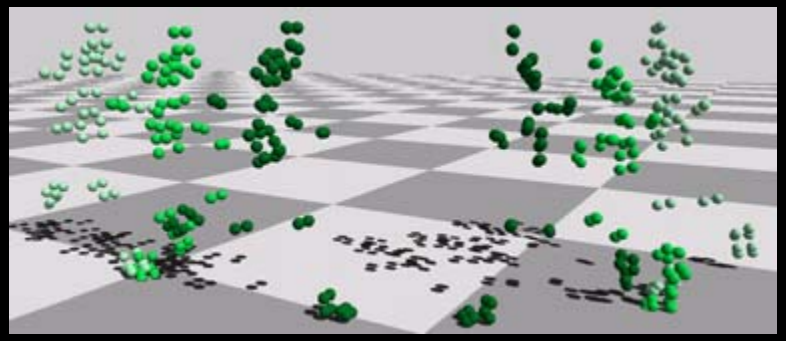
1) Initial frames



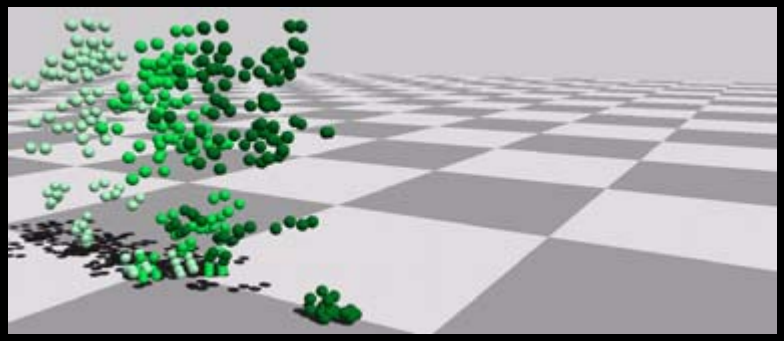
2) Extract windows



3) Convert to point clouds



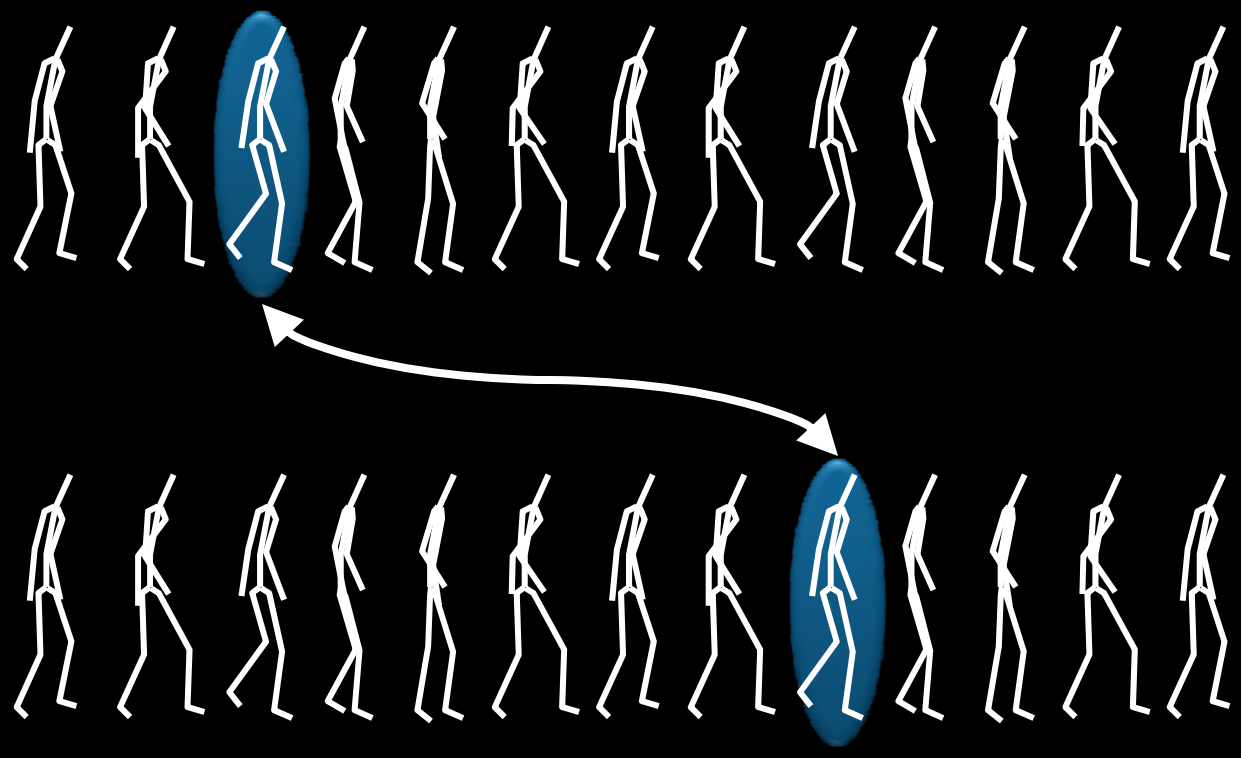
4) Align point clouds and sum squared distances



Kovar et al 2002, and others – see Kovar's thesis for discussion

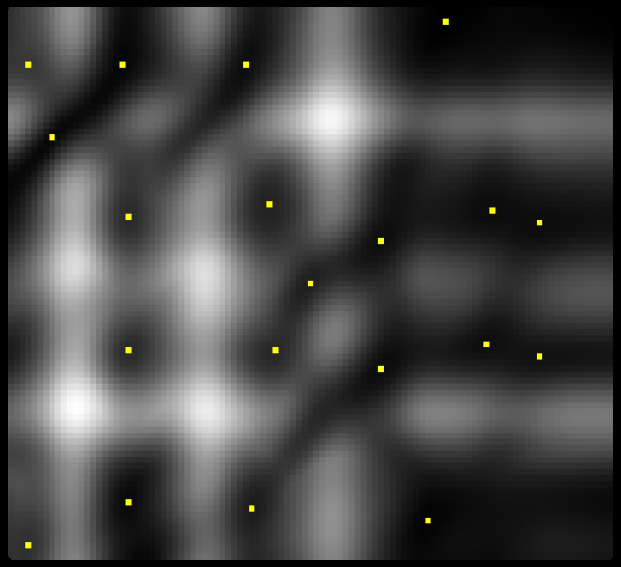
# Building a Motion Graph

- Find Matching States in Motions



# Finding Transition Points

Every pair of frames now has a distance.



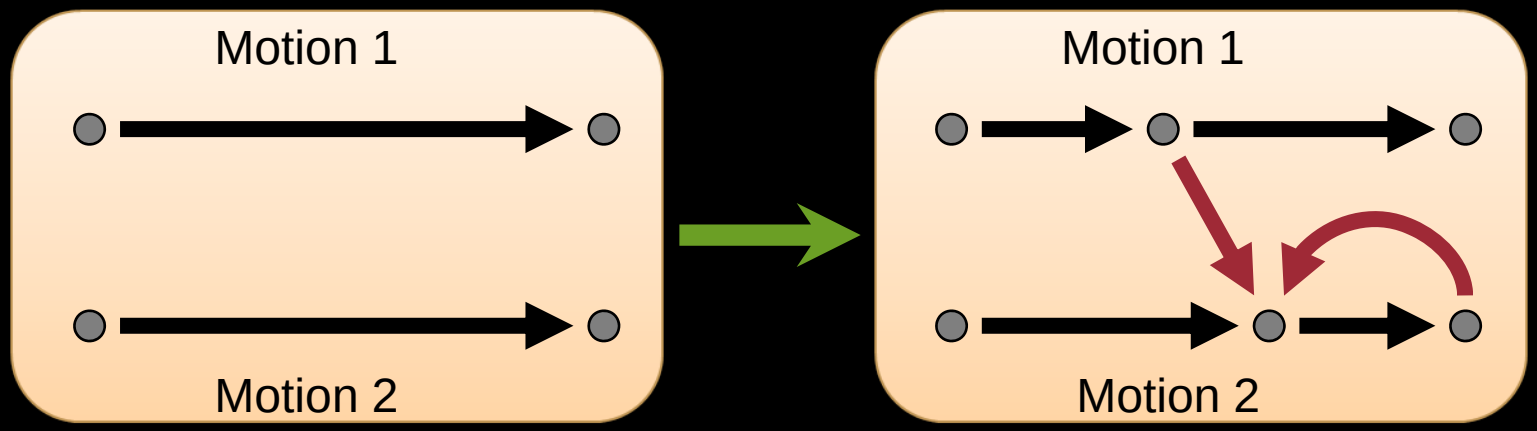
Transitions are local minima below a threshold.

# Motion Graphs

Kovar et al, Arikan&Forsyth, Lee et al. – All SIGGRAPH 02 and many other variants since

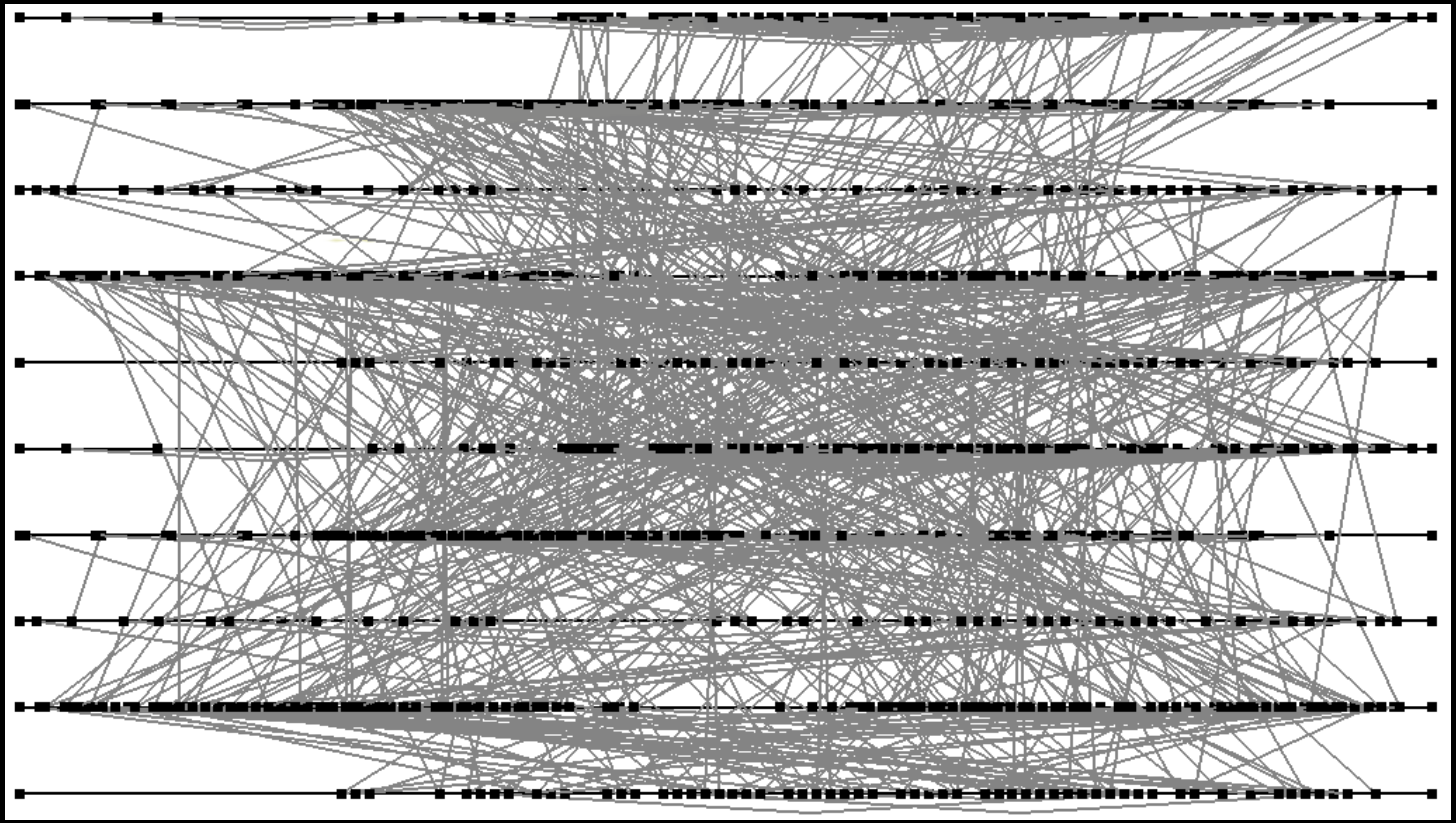
Start with a database of motions

Goal: add transitions at opportune points.

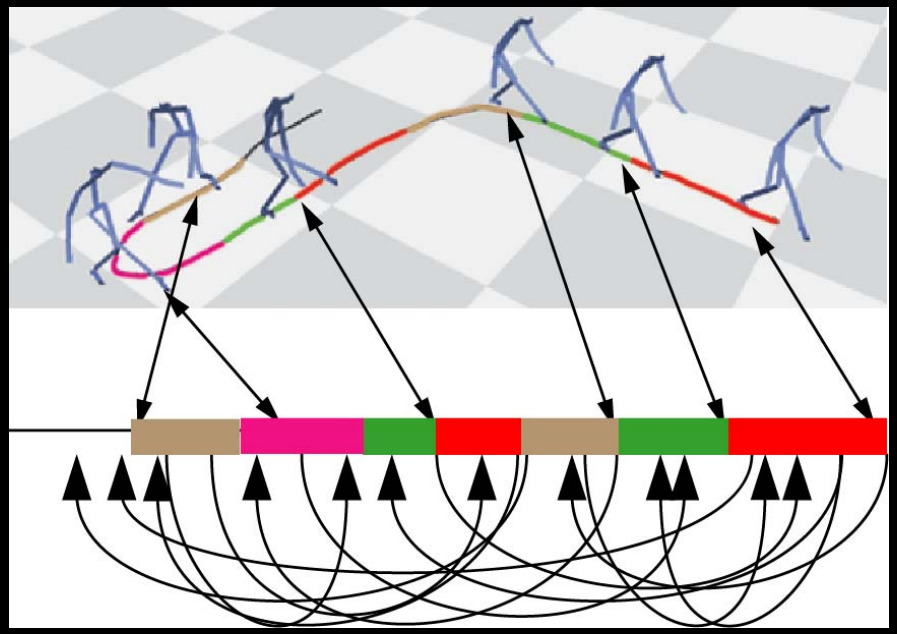


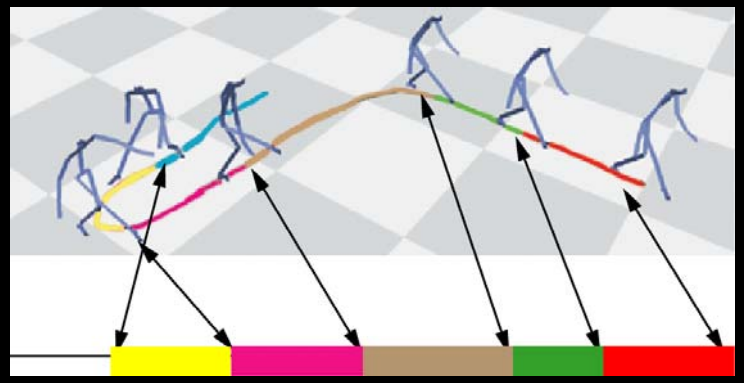
# Structure of Motion Graphs

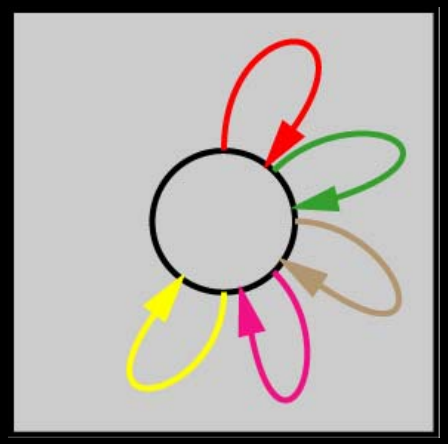
Opportunistically built graphs can be hard to search – especially for quick control



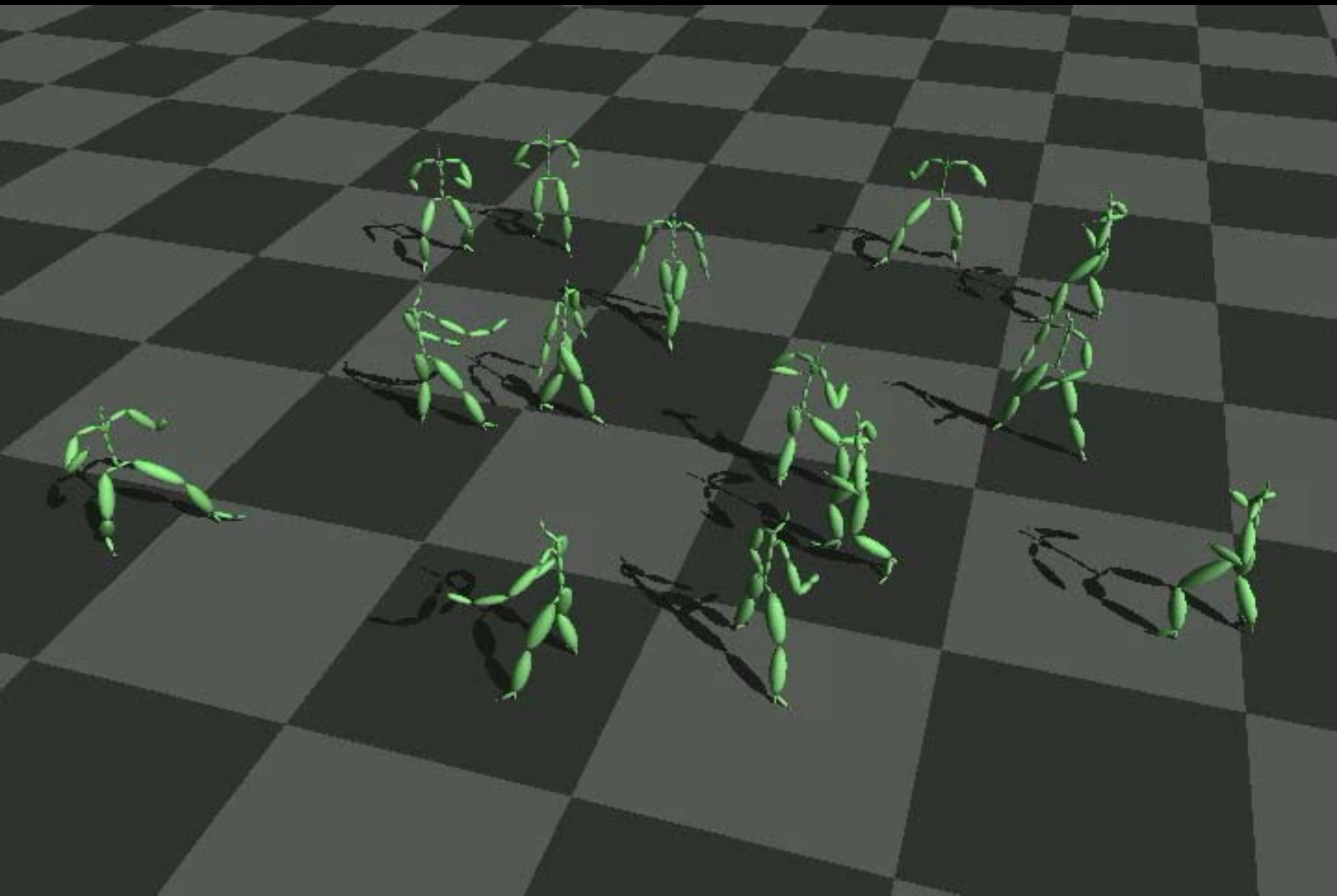
# Structured vs. Unstructured Graphs







Gleicher et al. I3D 2003



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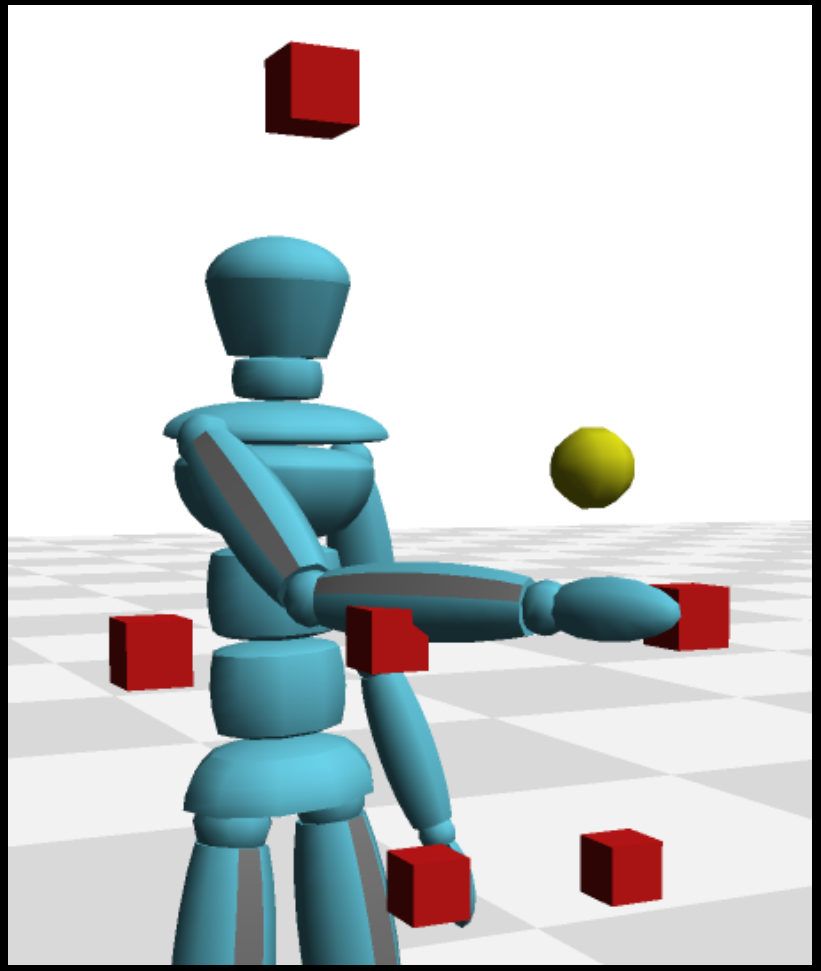
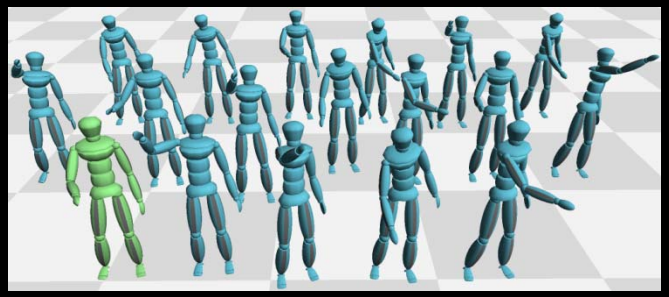
# Beyond discrete choices: Parameterization

- How to get a range of movements
- Given only a discrete set of examples
- Result is a motion – this is not just IK

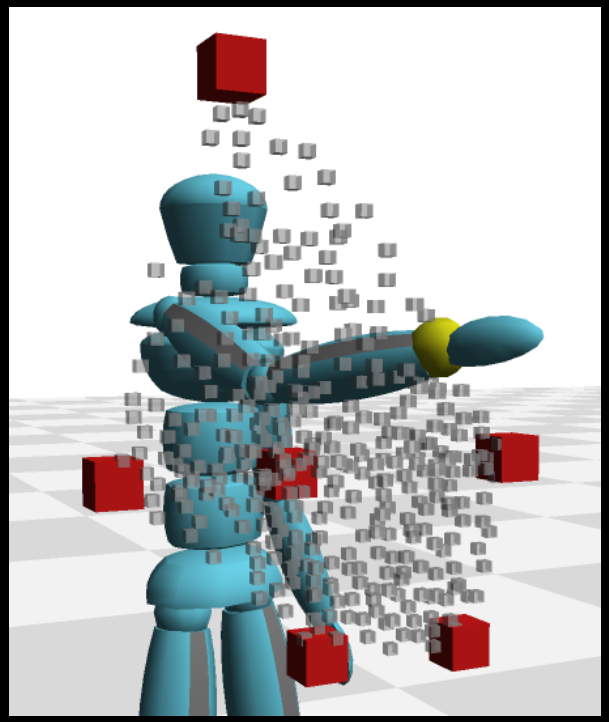


# Parameterization by Blending

- Use many examples
- Blend examples to get in-between motions



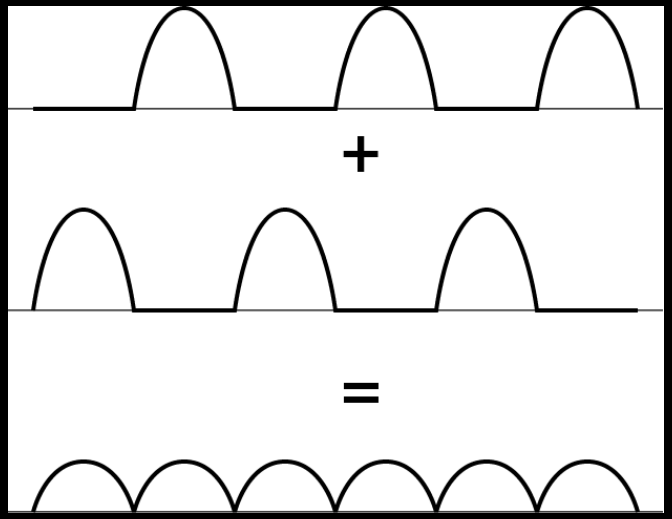
- General
- Gets specific effects
- Gets subtle coordinated effects

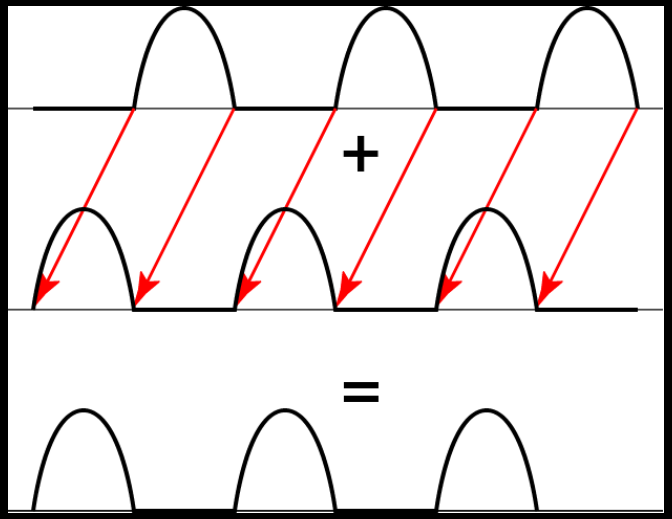


# Parameterization by blending

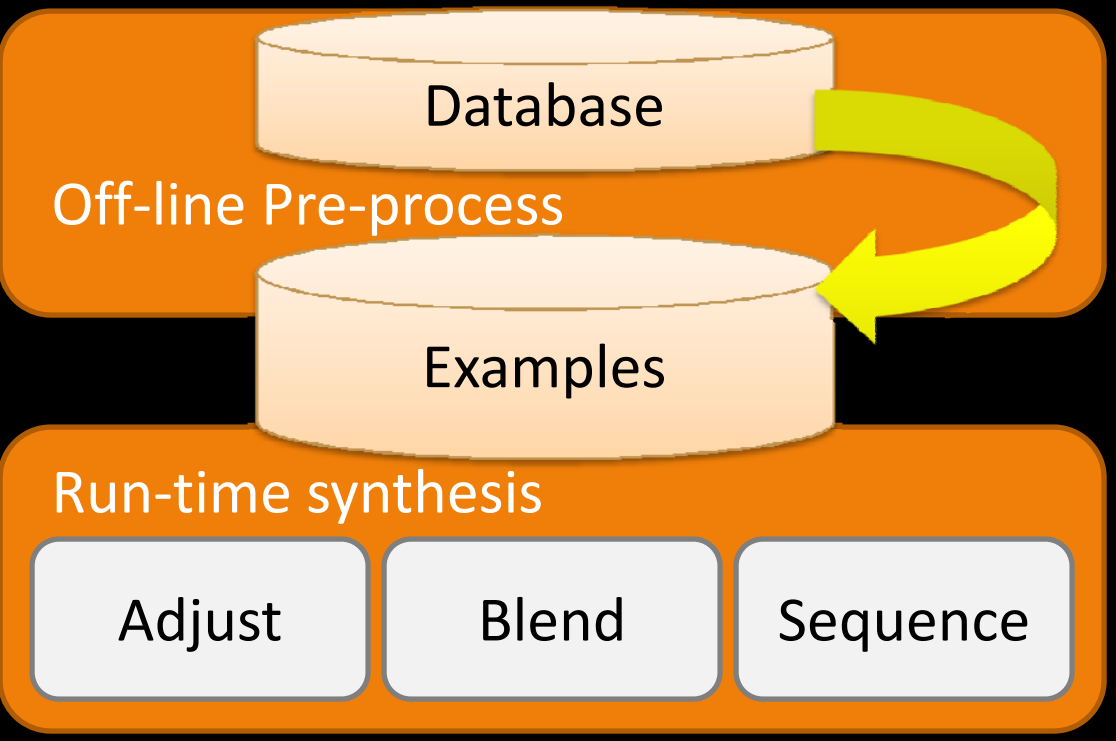
- In research since (at least) Rose et al ’98
- In games for a longer time

- Manual Process
  - Carefully aligned motions
  - Custom crafted parameterizations



# Basic Ideas of Synthesis-By-Example

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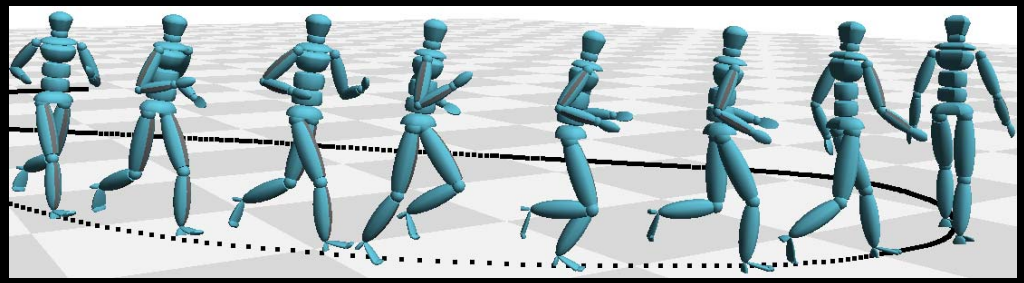

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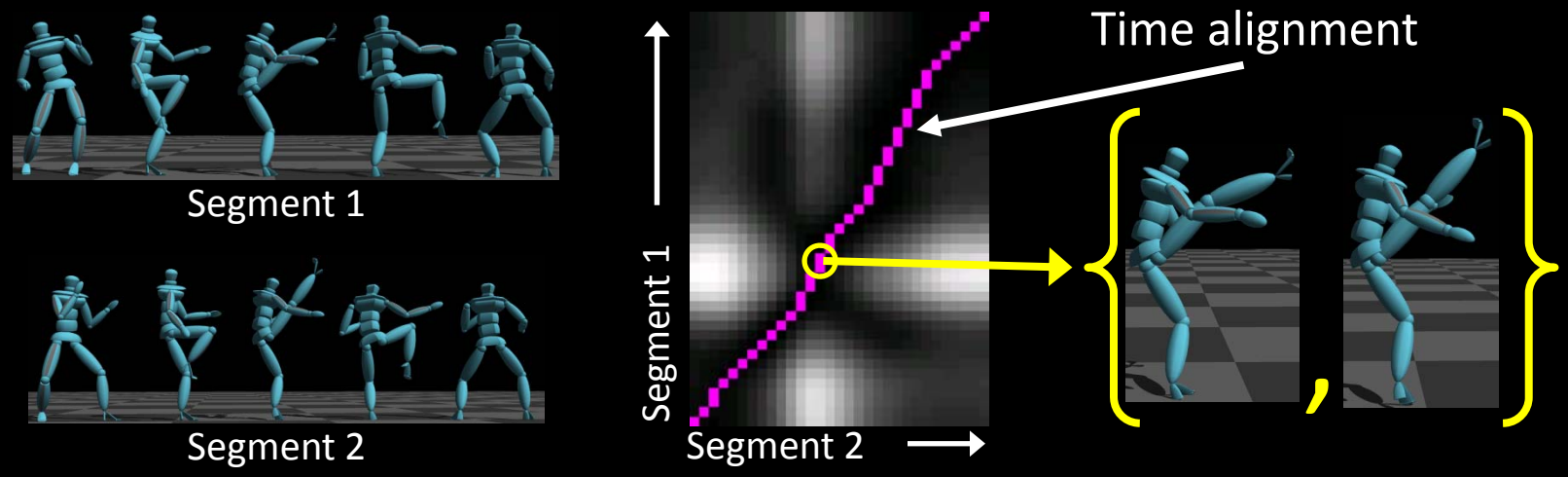
| **Assembly:** | Basic methods<br>Tweaks thrown in | Basic methods<br>Tweaks thrown in |
| **Control:** | Carefully crafted&tuned<br>Structured data makes problem easier | Parameterization |

# Automating Registration



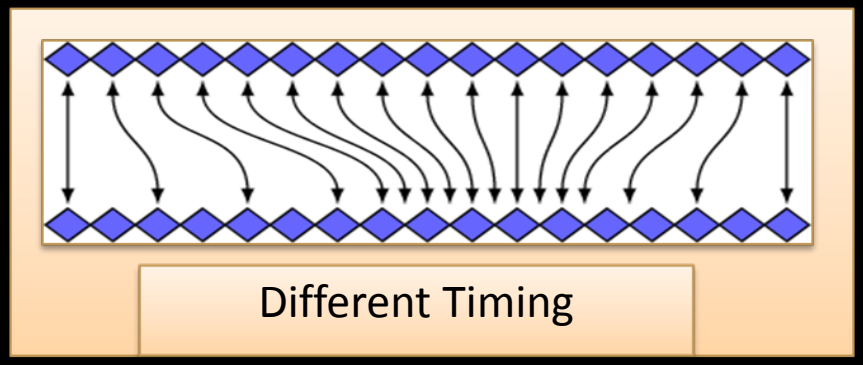

- Apex of kick corresponds
- Even though motions of different lengths

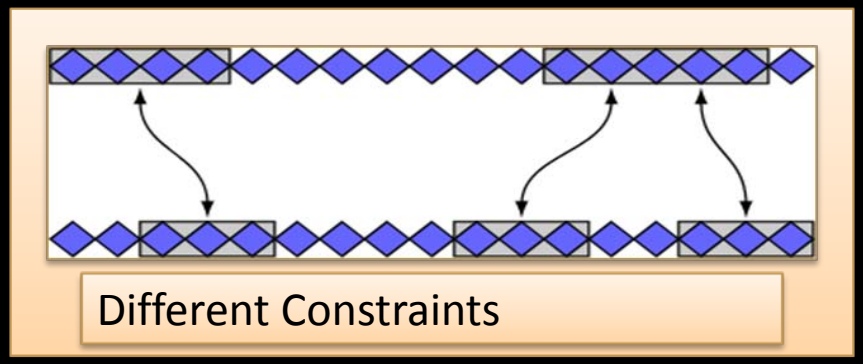
# Automating Blending

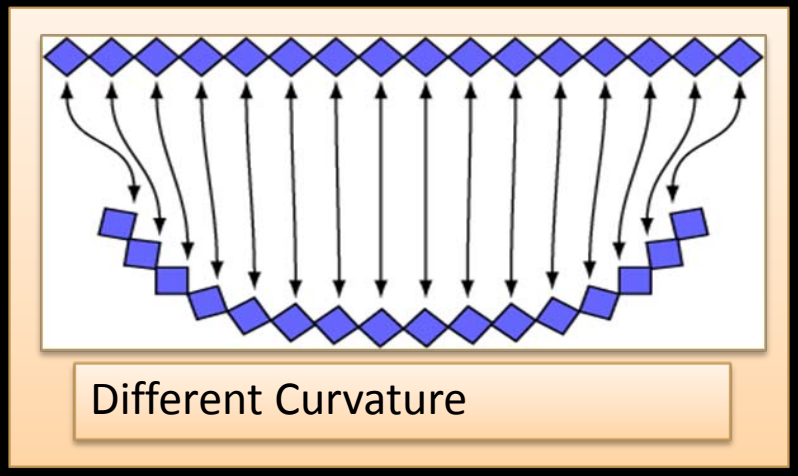
## Registration Curves

- Automatic Alignment
  - More detailed time warps
  - Other alignments (curvature, constraints)
- Allowed for more things to be blended

  (not just less effort)



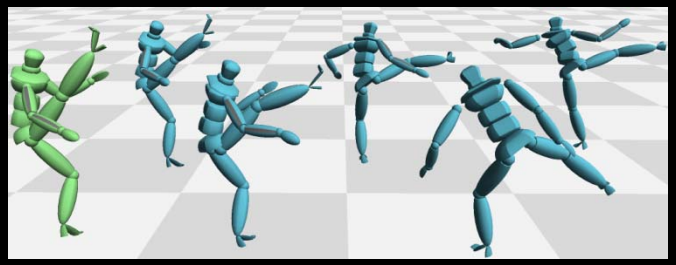




Kovar&Gleicher SCA '03

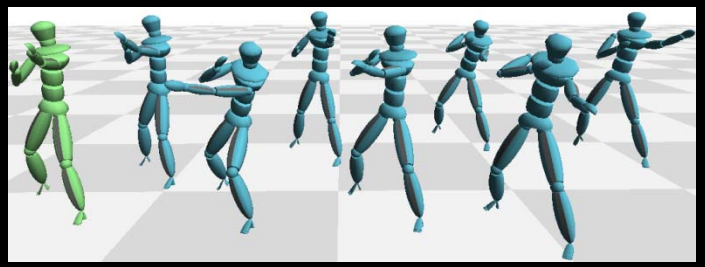
# Automatically Finding Examples

## Match Webs – Query by Example

- Search database for all motions that can be blended with an example (relatively efficiently)

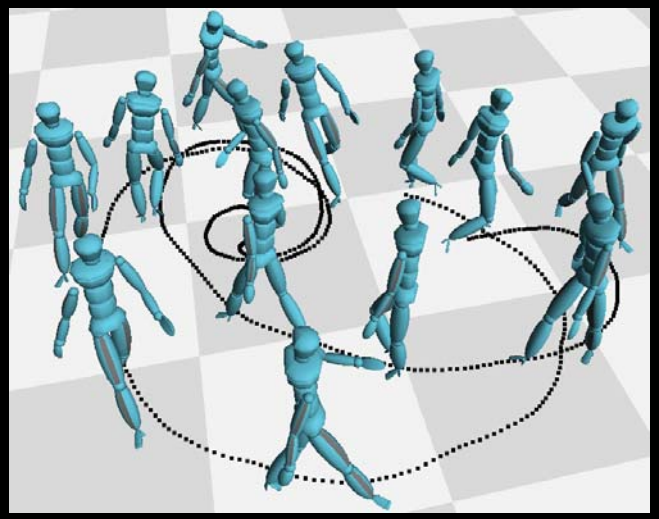


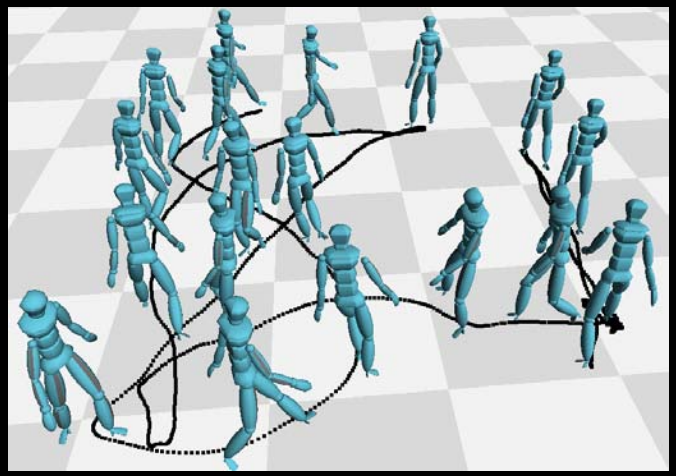
- Finds the registration for each match
- Automatically construct parameterization

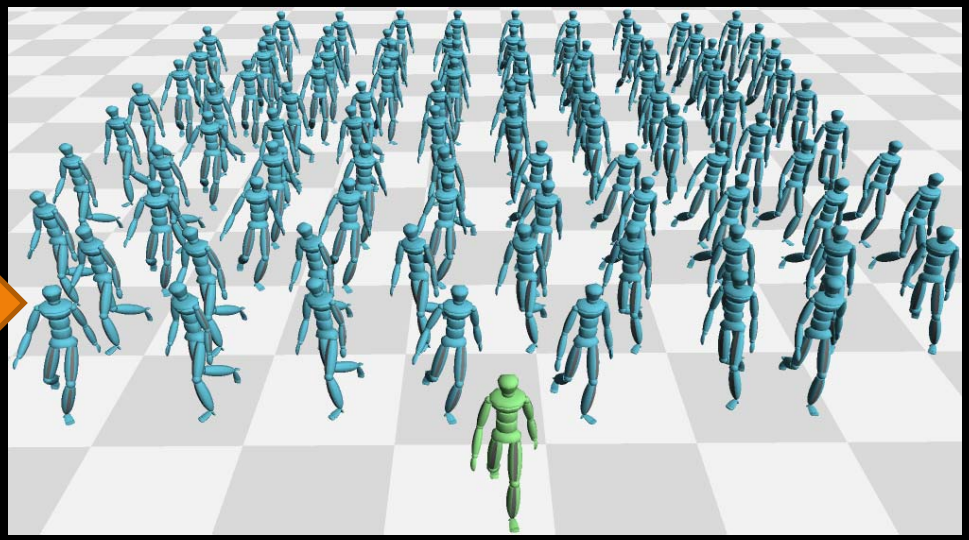


Kovar&Gleicher SIGGRAPH ‘04

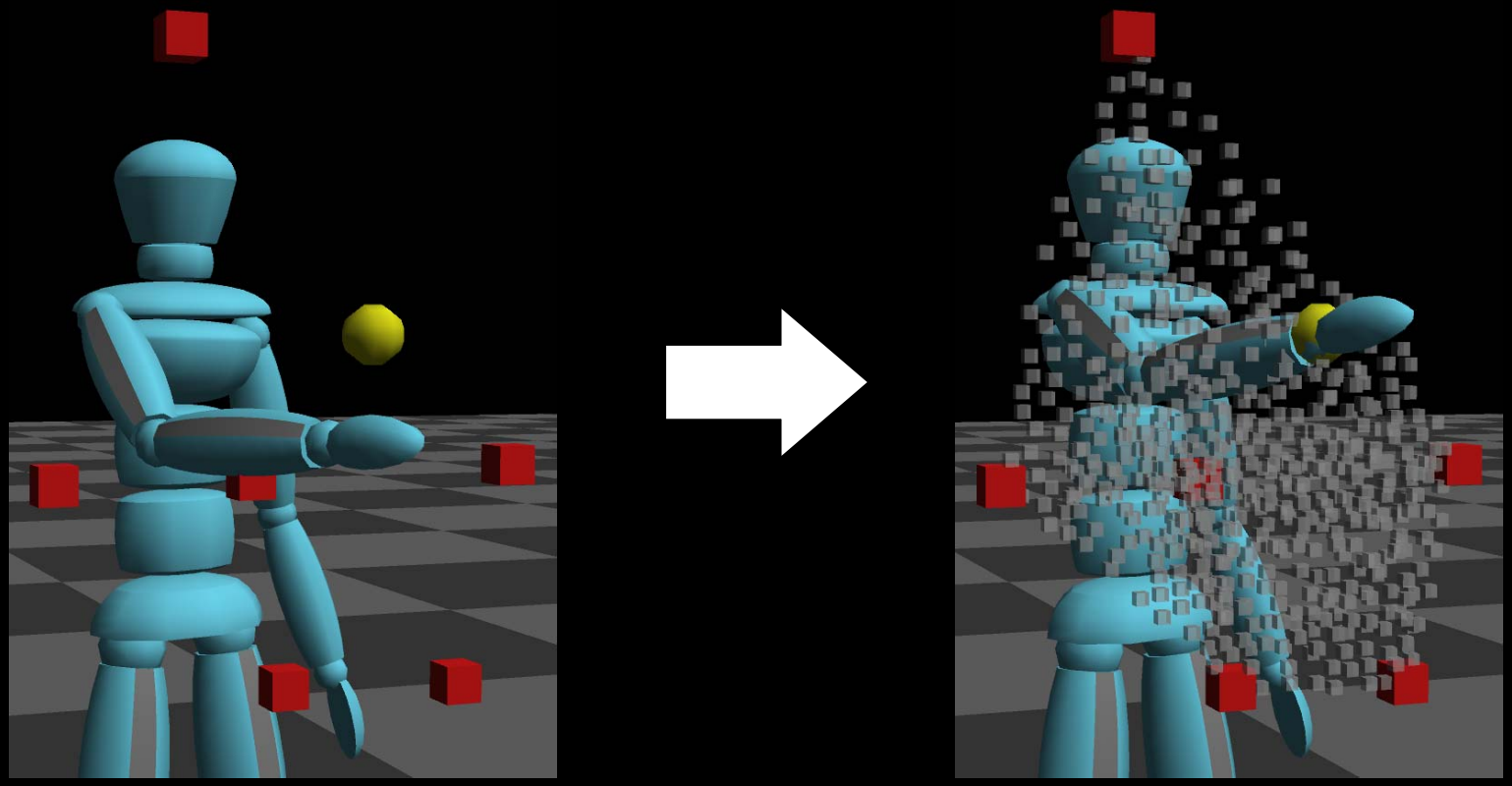
# Automatically find examples in data







# What amounts to blend?

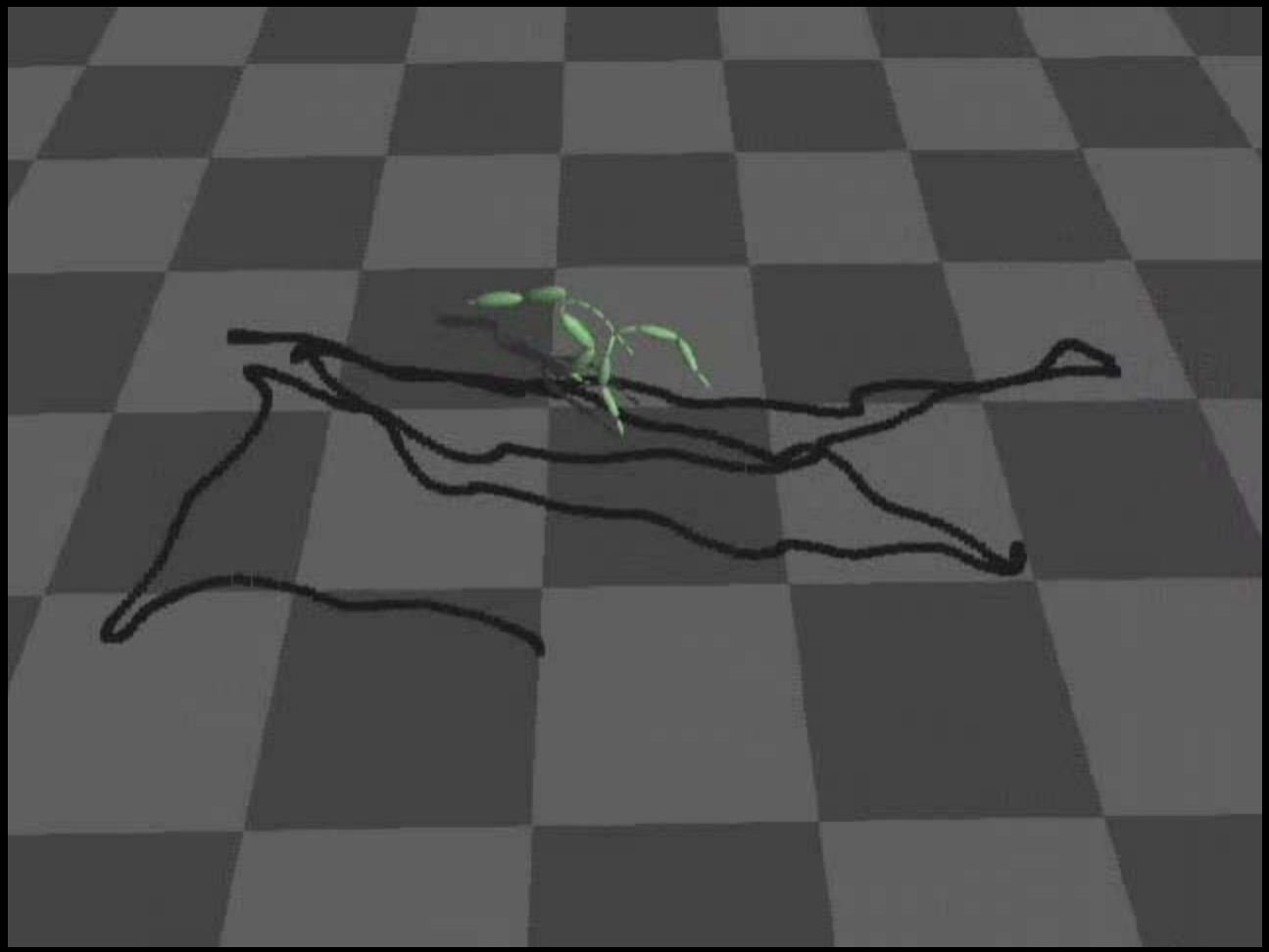


- Automatically map controls to blend weights
- Sampling + Scattered Data Interpolation

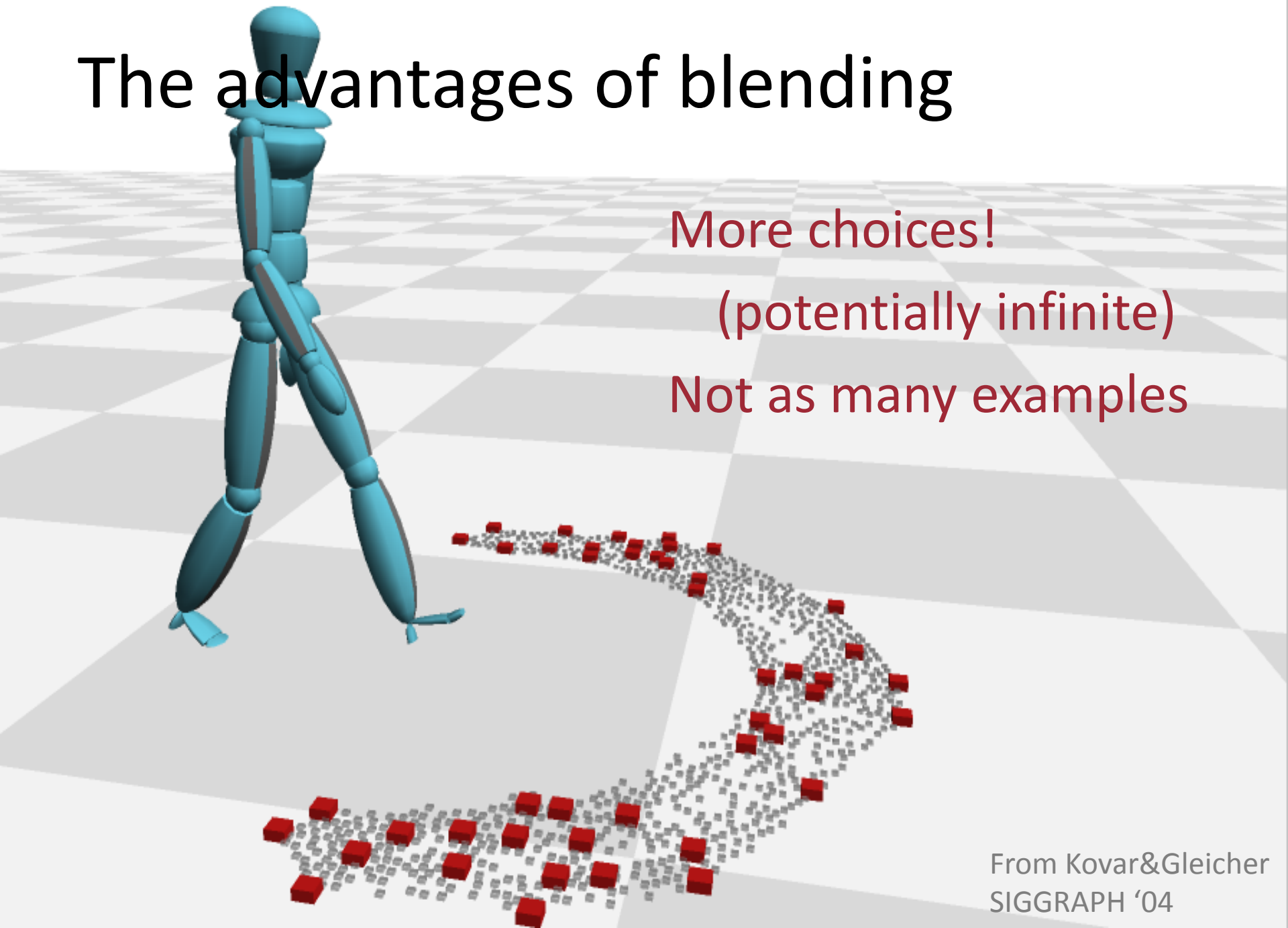
# Automation helps blending!

- Reduce amount of labor

- Makes larger example sets practical
- Allows for more complex blends
- More precise control
  - Better parameterizations
- Surprising what examples it can find



# The advantages of blending



More choices!

(potentially infinite)

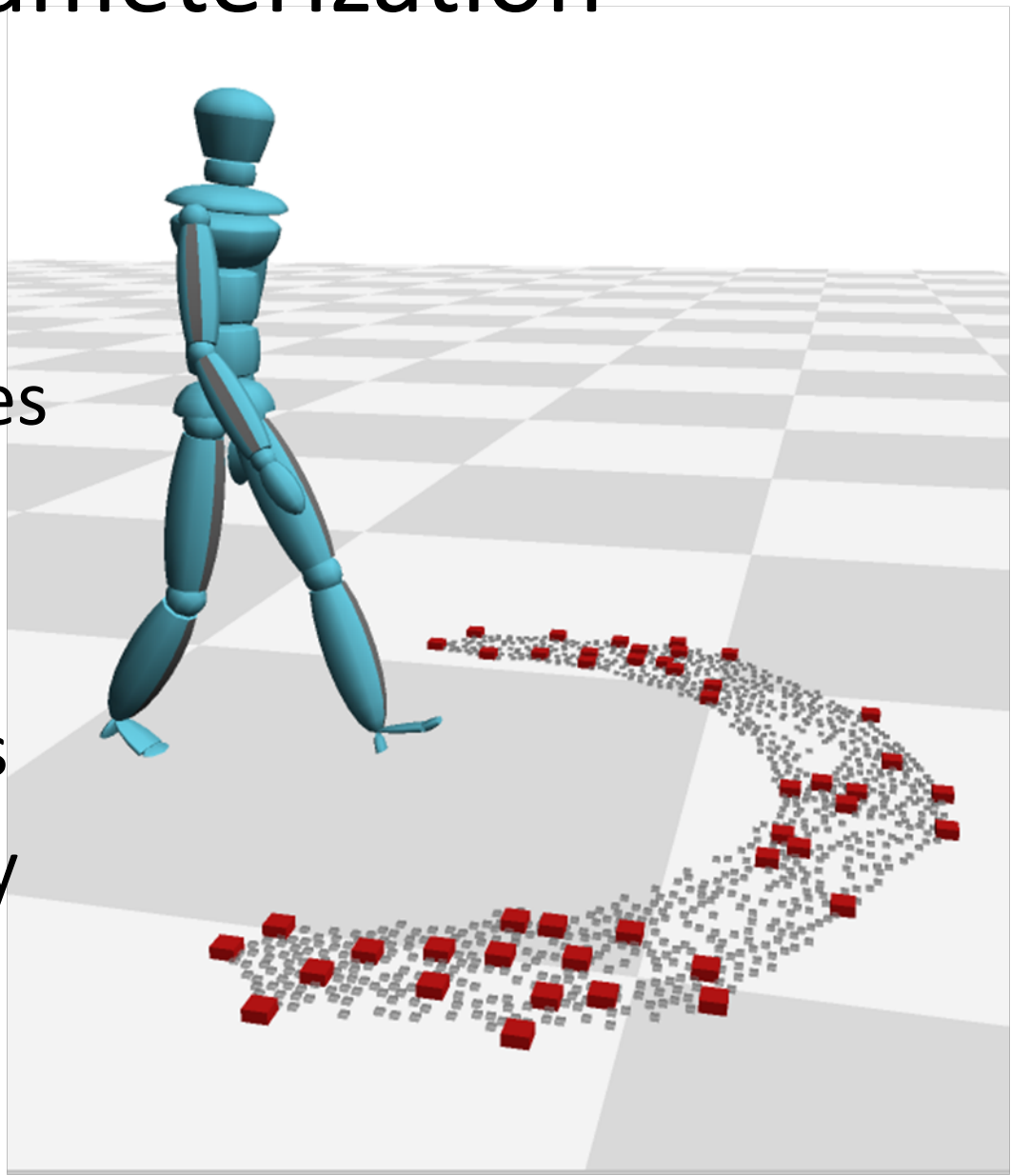
Not as many examples

From Kovar&Gleicher
SIGGRAPH '04

# Automated Parameterization

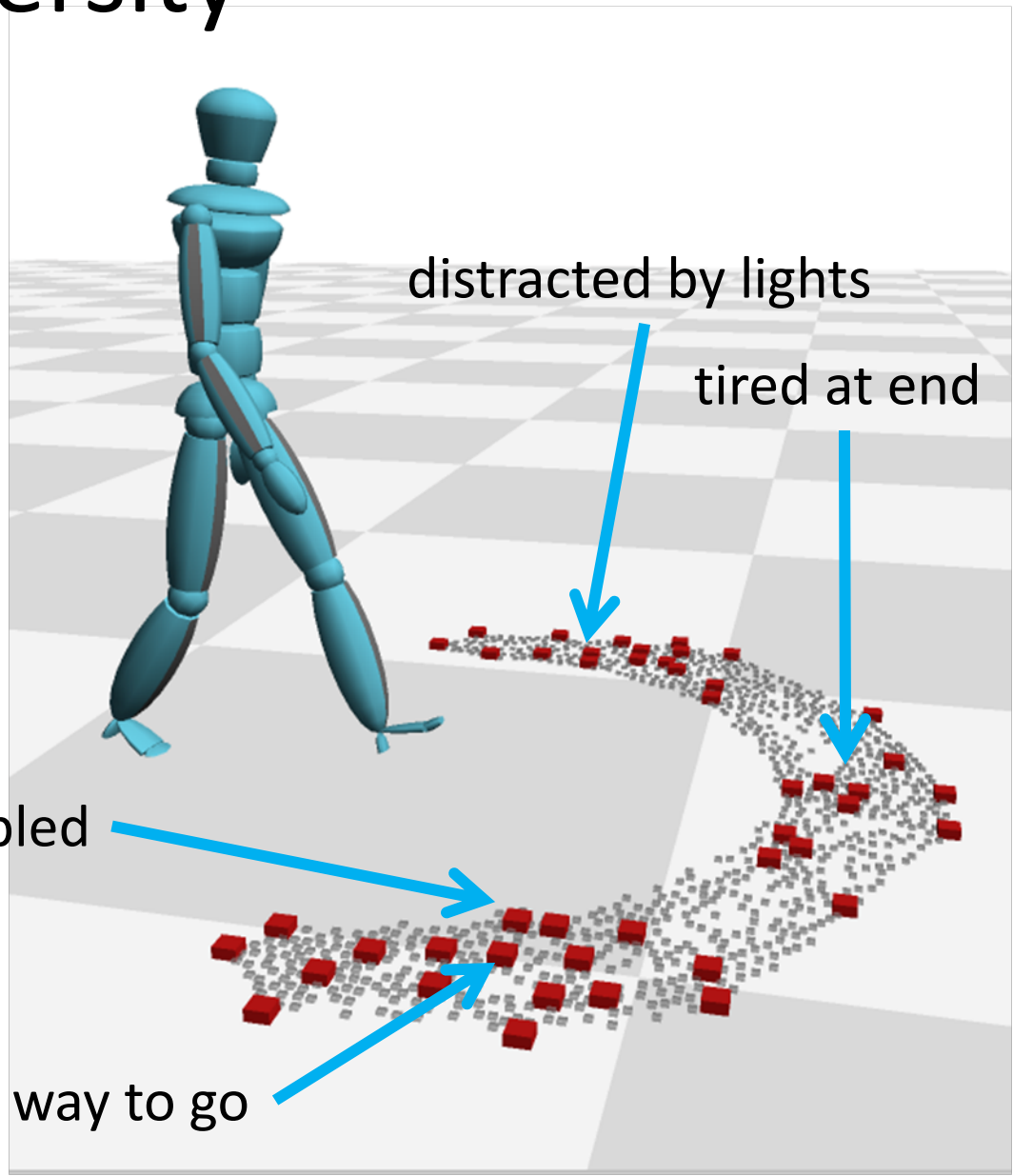
- Build space from all blendable examples
- Blend many examples

- Hard to QA
- Irregular data access
- Unintended diversity



# Unintended diversity

- Real data has variability
- Controlled capture reduces it
- An attraction of keyframing



# Roadmap

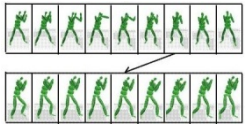
- Basics of Synthesis-By-Example (SBE)
  - Concatenation as an example
- SBE in Practice vs. Research
  - Blending-based parameterization as an example
- Creating controllable characters
  - Parametric graphs as an example

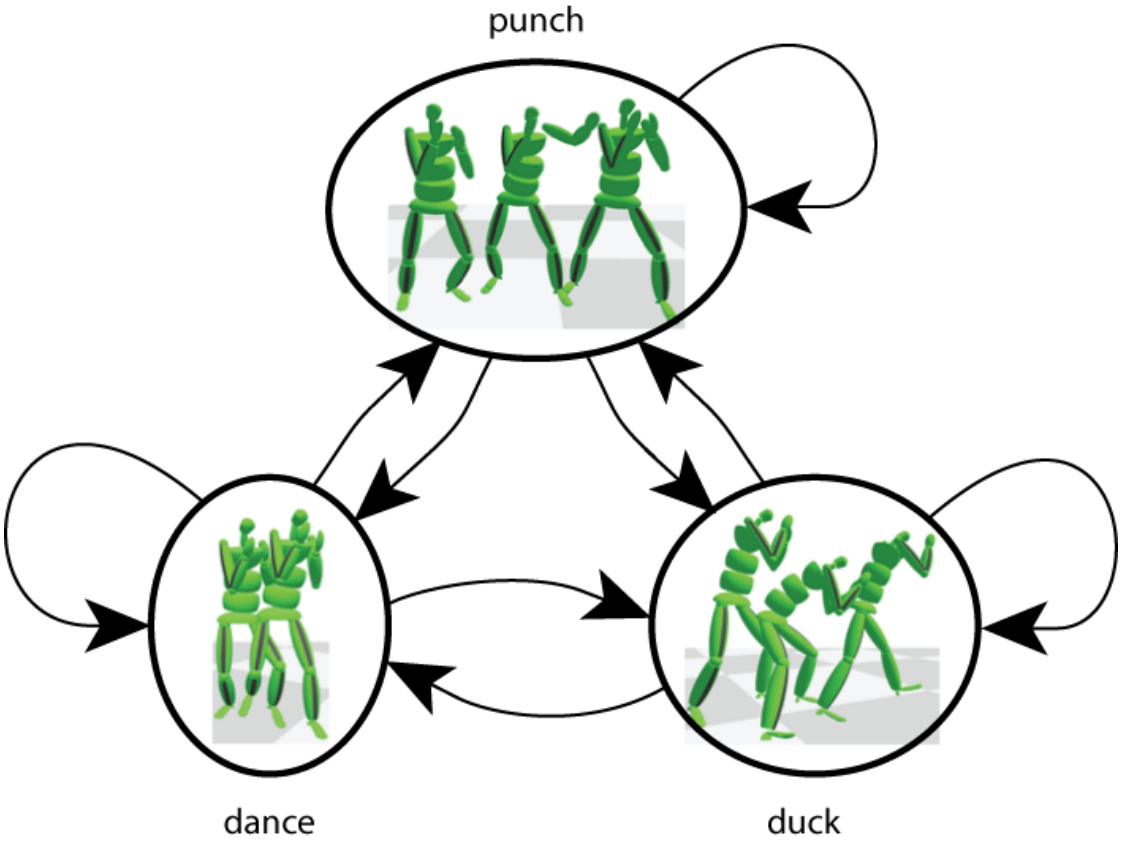
# Parametric Motion Graphs

## Turning parametric clips into a character

**Nodes:** Represent  Parametric  Motion Spaces

**Edges:** Describe How to Transition Between These Spaces

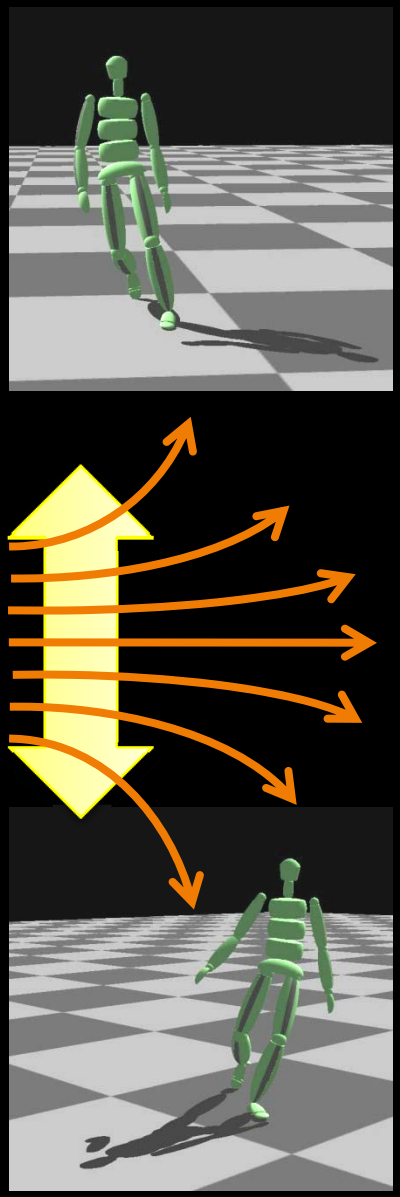




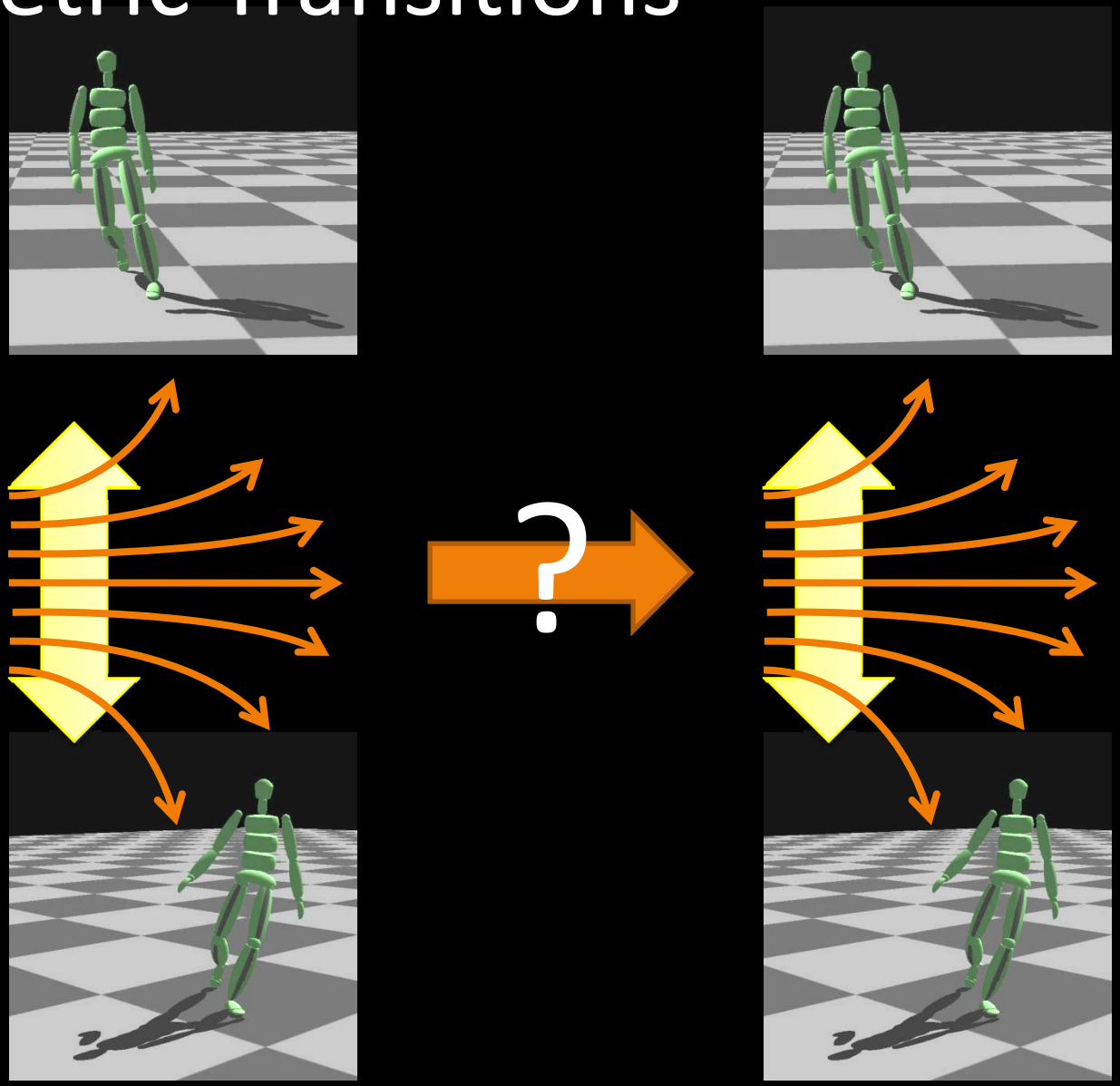

Like everything else, these have been used in games.
Variants have existing for a long time.

# Parametric Graphs

- Each node is a range of motions
- Each node has a range of beginnings and endings



# Parametric Transitions

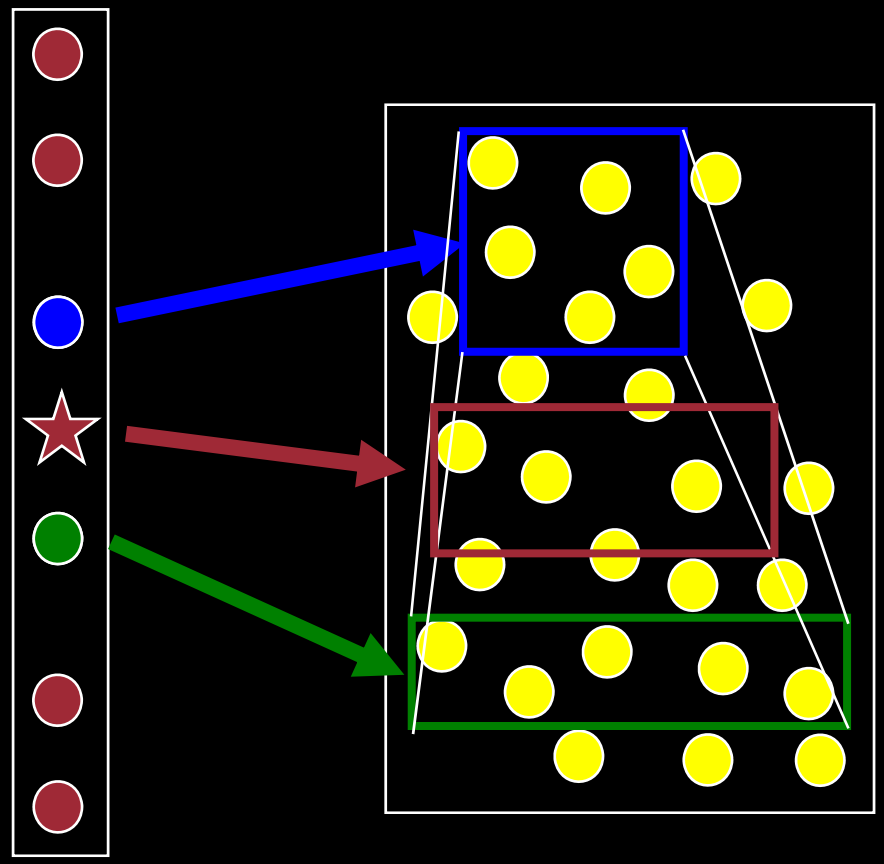


# How to make transitions between parametric spaces?

- In practice (?)
  - Build spaces that just work
  - Accept the occasional bad blend
- In research
  - Force common pose (Shin&Oh SCA ’06)
  - Find allowable ranges (Heck&Gleicher I3D ‘07)

# Method: Data Extraction

***K-Nearest Neighbor Interpolation***




Interactively Controlled Running

# Review: Synthesis-By-Example

- Build motions from examples

Simple building blocks

- Concatenation
- Blending

- Research: Automation and advanced control

Why is Synthesis-By-Example so pervasive in games?

# Advantage of Synthesis-by-Example

- Actors* are directable (* or good keyframe animators)
  - Can do a range of things a range of ways
  - Consistency in performance
  - Relatively easy to get desired examples

- Get different motions, styles, subtleties

  Without having to model each one
- Easier to scale to diverse repertoire, with acting subtleties, get the directors intent, …

# Disadvantage of SBE: No Model!

- Rely on exa
  - Which ma
- Limited ada
  - Simple me
  - Aren't res
- Larger repe
- Scalability?

**2 ways to make things better:**

1. Use more examples
2. Use  examples better

#2 is more likely to scale up

Lessons of #1 may tell us something

Where does motion come from?

# Two Approaches

**Model-Bas le**

- Generat otions algorith a
- Craft m gorithms

- Motion y comes by cleve a

- Develop models per motion
- Have a motion model
  - Generate more motion

- No per-motion models
- No motion model
  - Limited adaptability

Approach 2 ½:
Use examples to derive models

Does this get the best (or worst) of both?

# Does this help real games?

- Automation means less work
  - Possible for academic to do it (no artists!)
  - But artists don’t like to give up control / QA
- Automation can do more complex things
  - Much larger example sets
  - Much more complex parameterizations

# Thanks

- The students who did the work
  - Lucas Kovar, Rachel Heck, Mankyu Sung, …
- The rest of our group
- The people who supported us financially
  - Original research supported by NSF, UW Grad School
- The people who gave us data and challenges
  - House of Moves / Vicon (Taylor Wilson), EA, Demian Gordon, Rockstar Vienna, (and a whole lot of others)

- You – for listening