Synthesis by Example

Connecting Motion Planning and Example-based Movement

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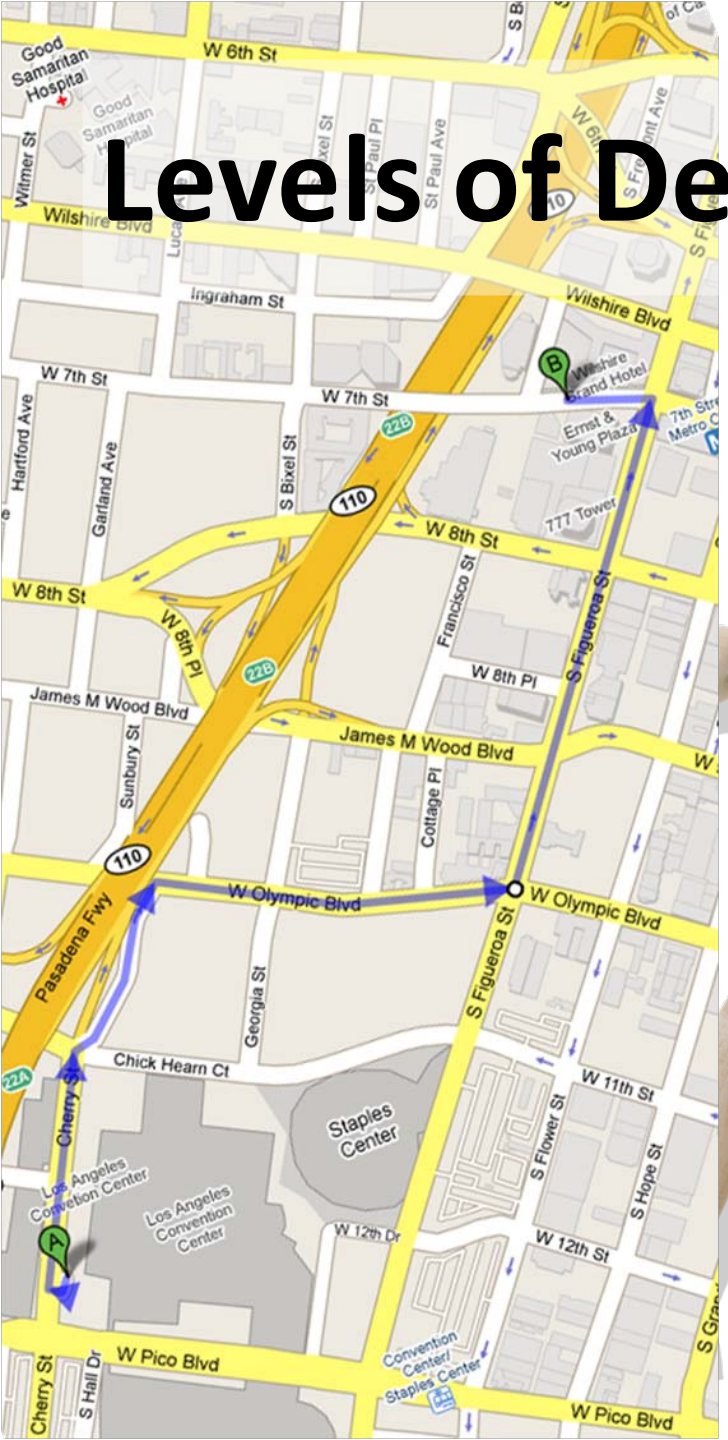
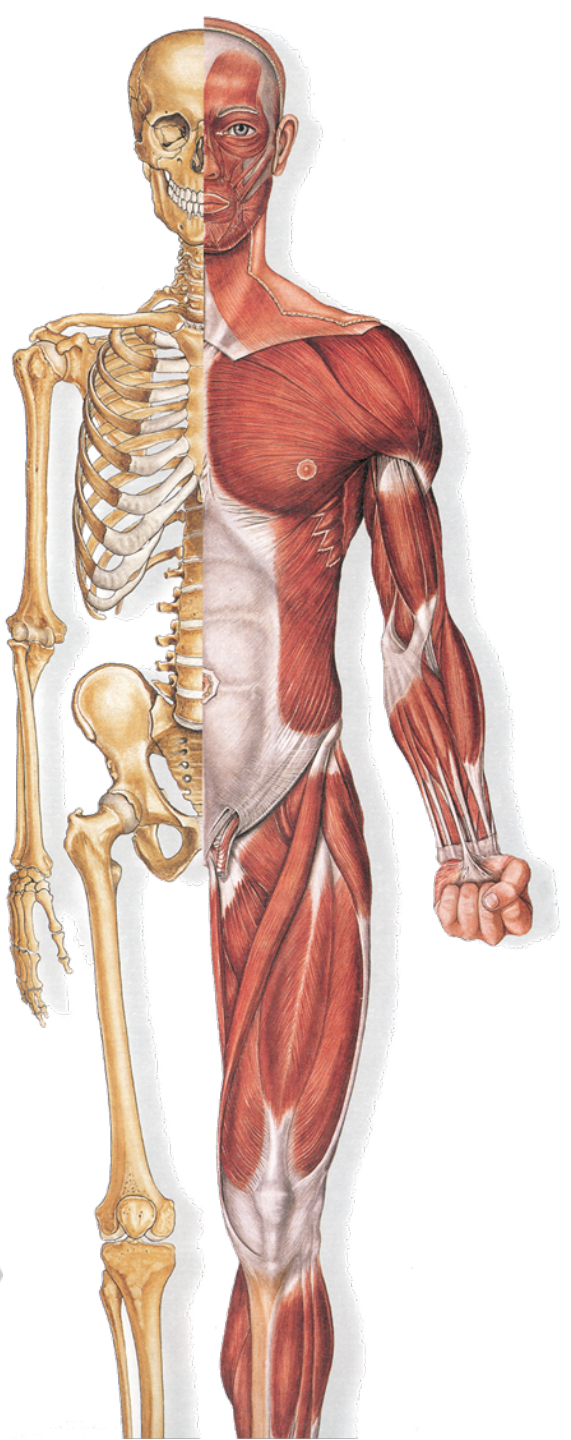
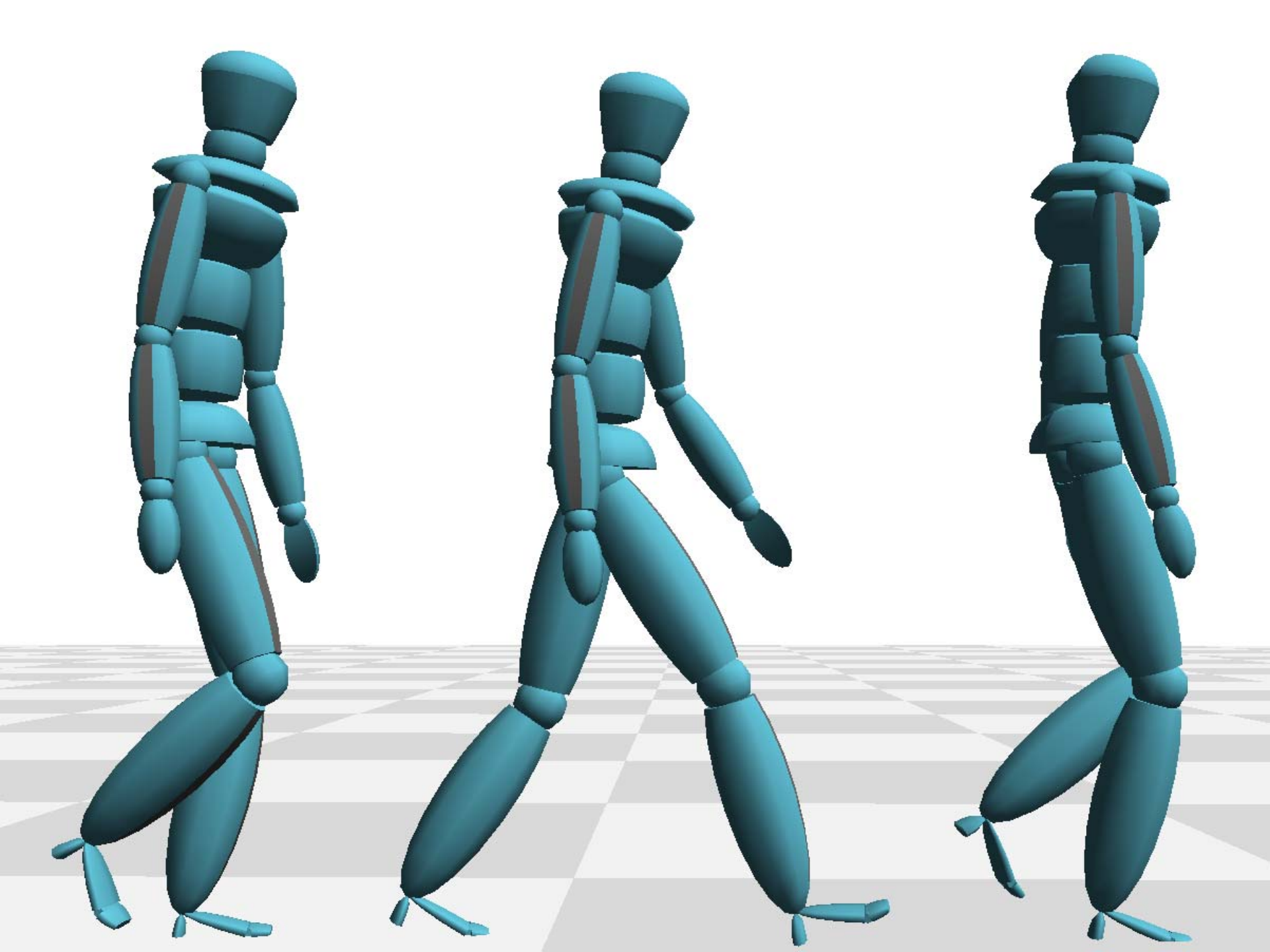
What is Motion Synthesis?

Motion Synthesis is the creation of the detailed trajectories of the parts of the character

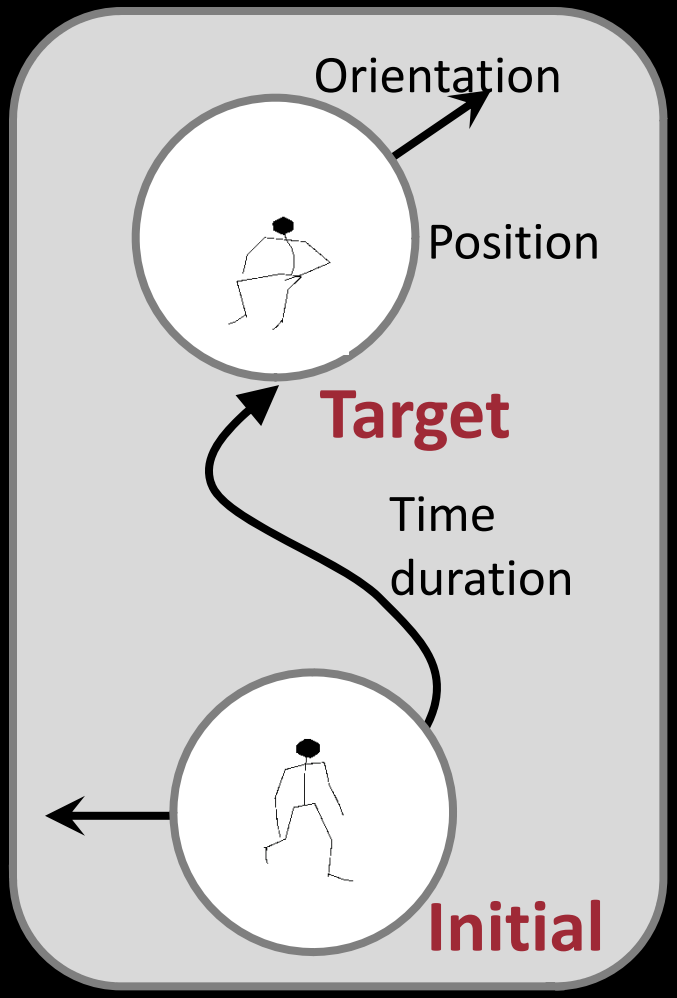
Levels of Detail



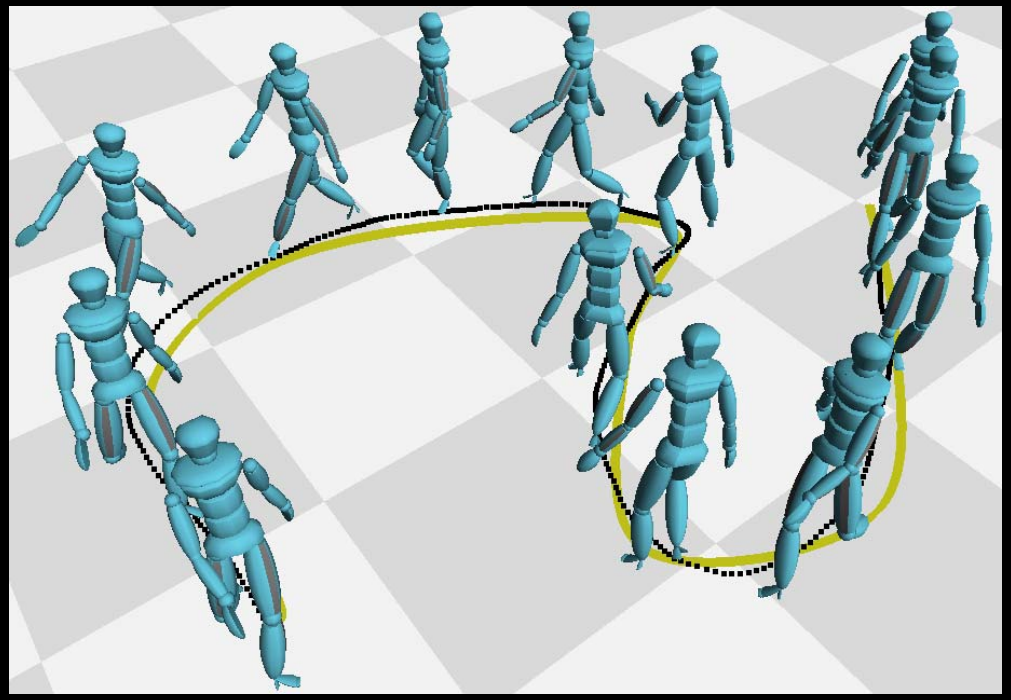




Planning vs. Synthesis



Planning



Synthesis

Key Point:

To get (good) detailed movements that meet high level goals, we need to combine approaches

Neither synthesis or planning methods can do it alone

One Challenge:
The Diversity and Complexity of Human Movement

Where does motion come from?

A Continuum of Approaches

Model – Based / Algorithmic

Use understanding of motions to devise models

Data-Driven / Example-Based

Use recorded data (without trying to understand it)

Example-Based Synthesis

Capture the detail, subtlety and complexity

Actors*:

- Can do complex things
- Can do many things
- Are directable

It is *relatively* easy to get examples

(* or keyframe animators)

Where does motion come from?

A **Continuum** of Approaches

Model – Based / Algorithmic

More complex / specific algorithms

Data-Driven / Example-Based

More use of data (generic algorithms)

Where does motion come from?

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

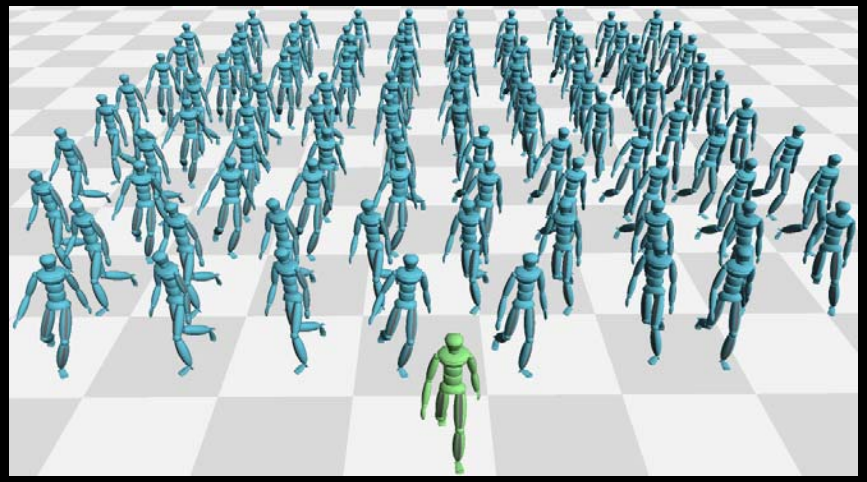
- Assemble new motions from example data
- Simple, generic algorithms

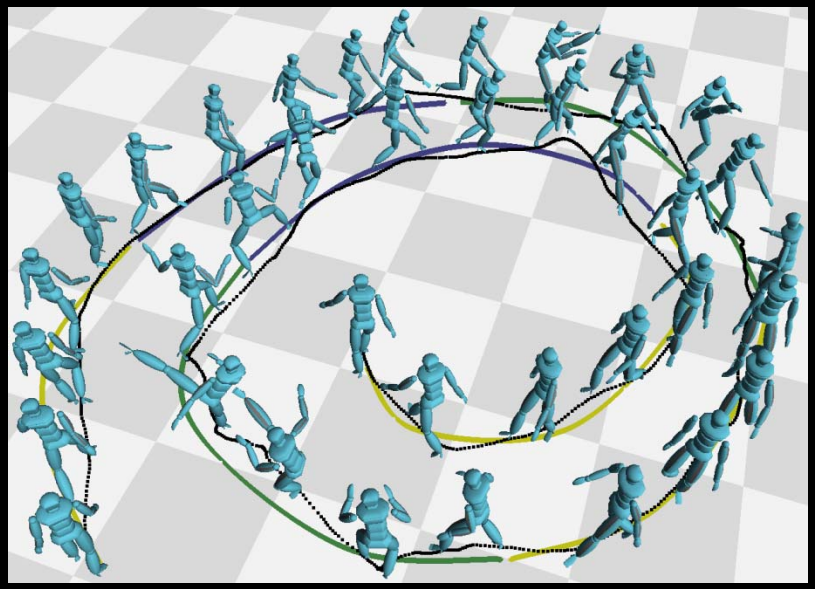
- Motion complexity comes from example data

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

Synthesis By Example

Create what you need from what you have



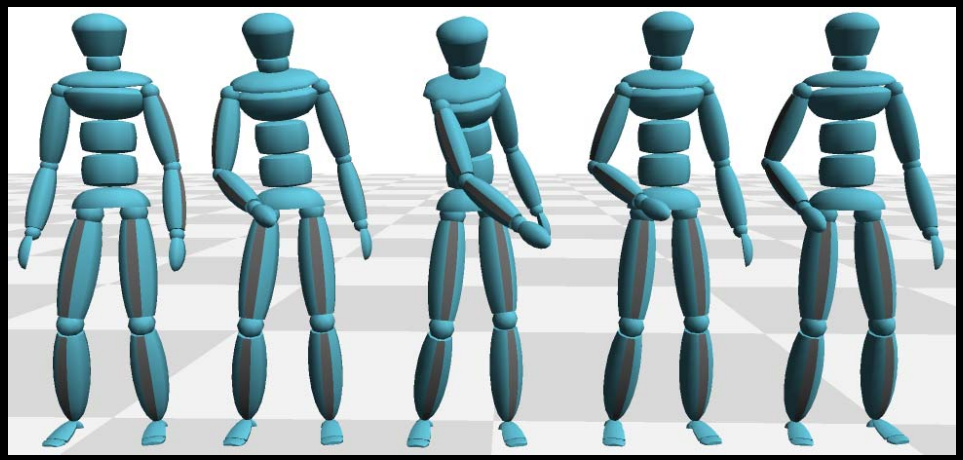


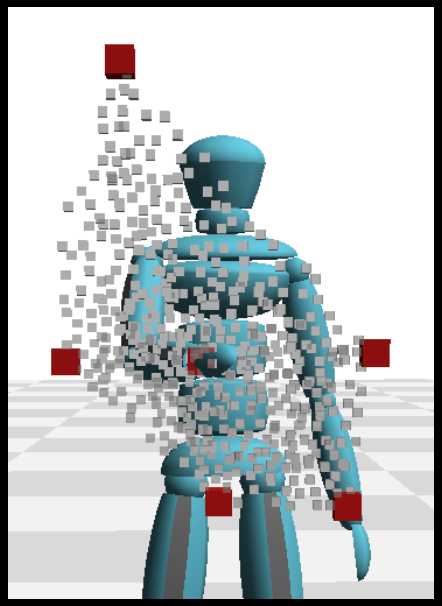
Have: Lots of Clips

Want: Long Streams

Synthesis By Example

Create what you need from what you have

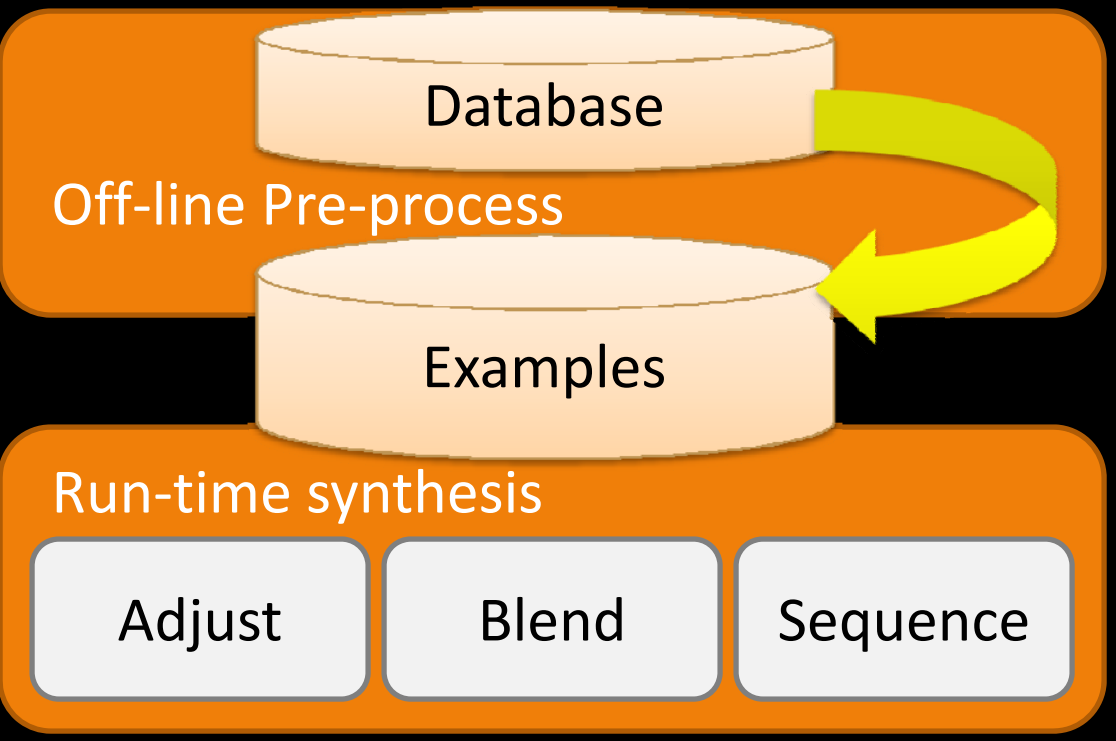




Have: Lots of Clips
(Discrete set)

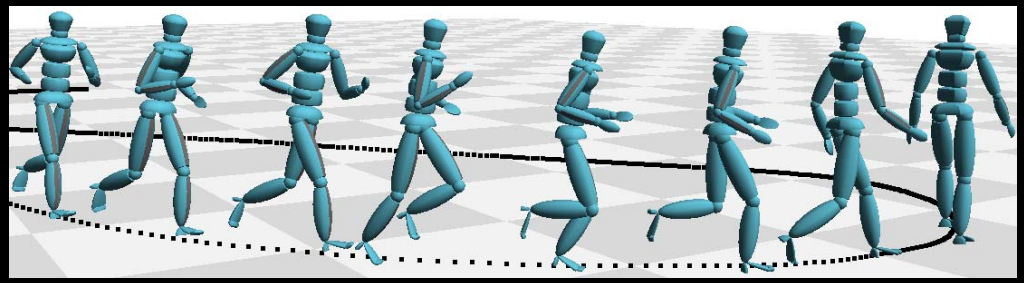
Want: Range
(Continuous)

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, …)

One SBE Approach

Concatenative Synthesis

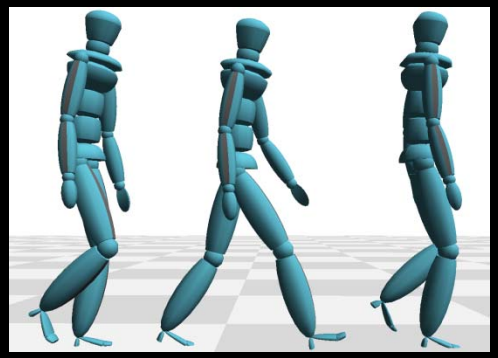
- Play clip after clip
- Discrete choices at every clip

- Preparation: find clips, find connections
- Assembly: concatenation, transitions
- Control: choose which clips to play

- More modern methods are continuous

Concatenation

Put clip after clip after clip …



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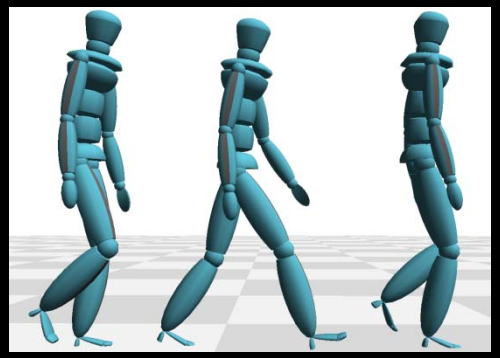

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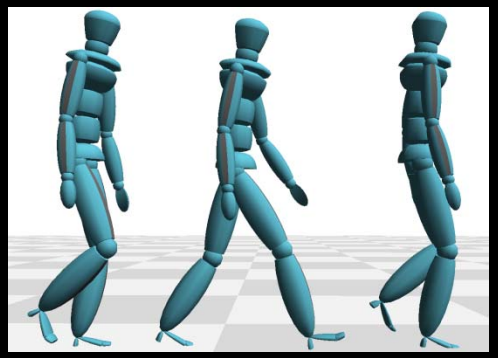
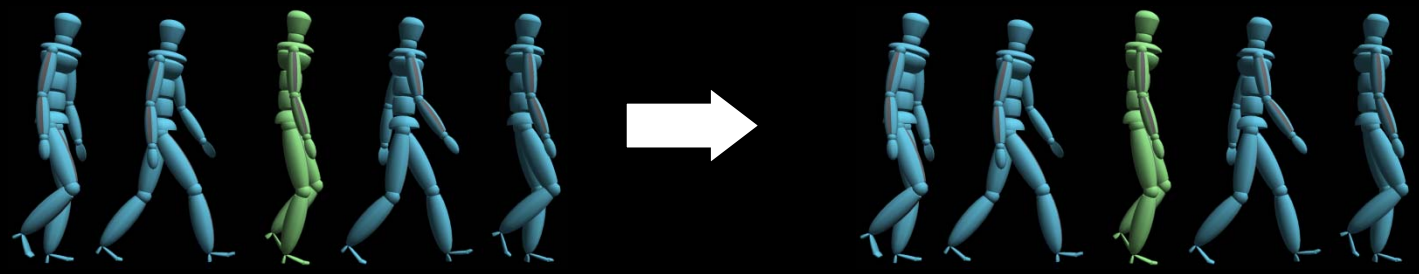
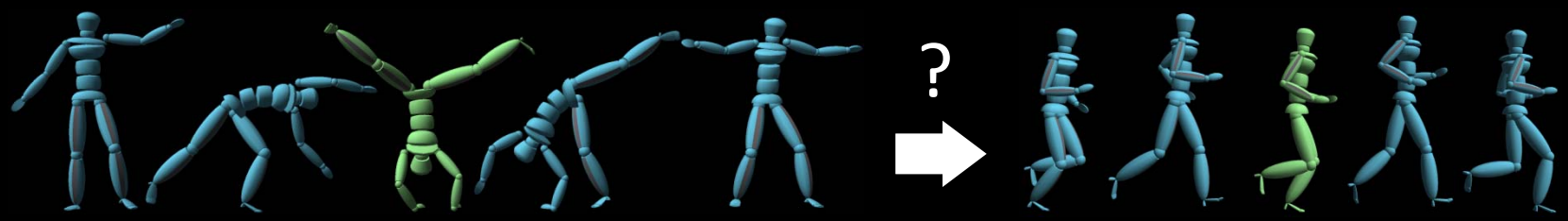


Transitions

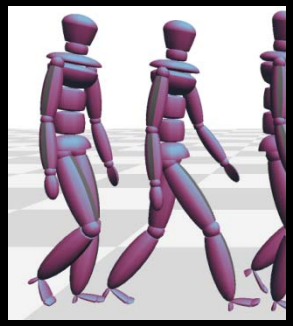
Some transitions are easy



Some transitions are hard



Simple Transition Methods



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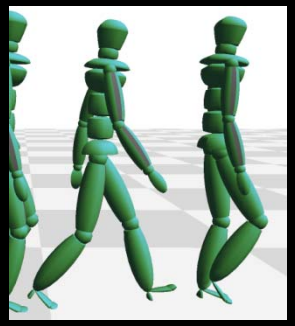
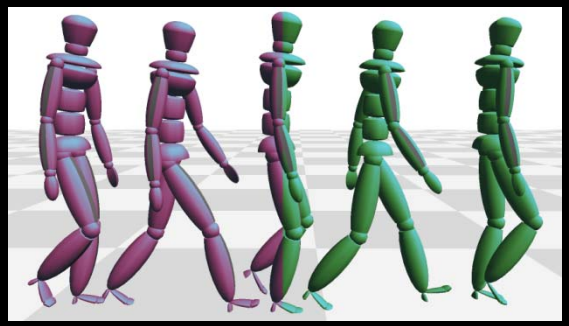
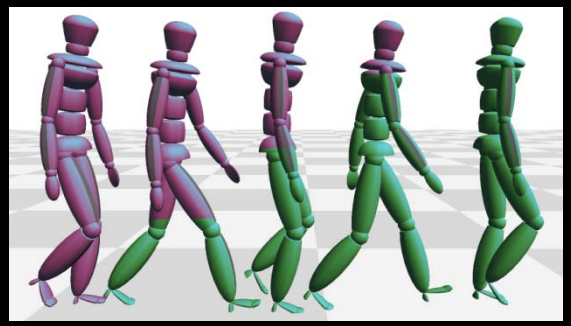




Cut transition



Blend Transition

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

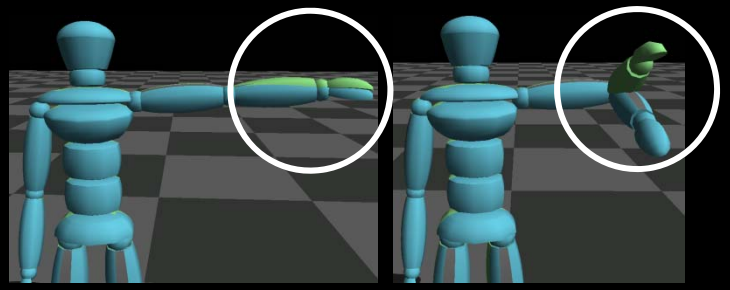
In Research (starting around 2002)

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

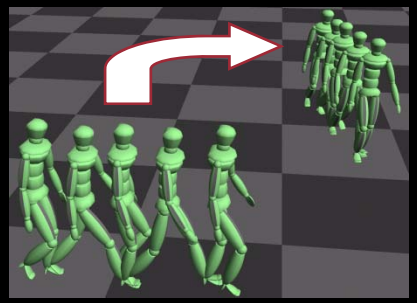
Kovar et al, Arikan&Forsyth, Lee et al. – All SIGGRAPH 02

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



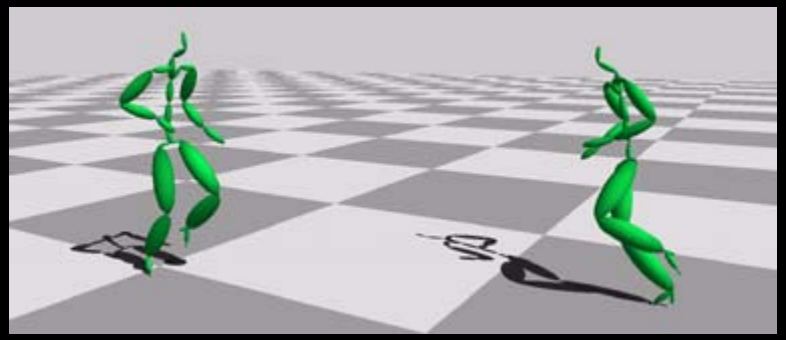
- Need coordinate invariance
  - Different camera ≠ different motion!



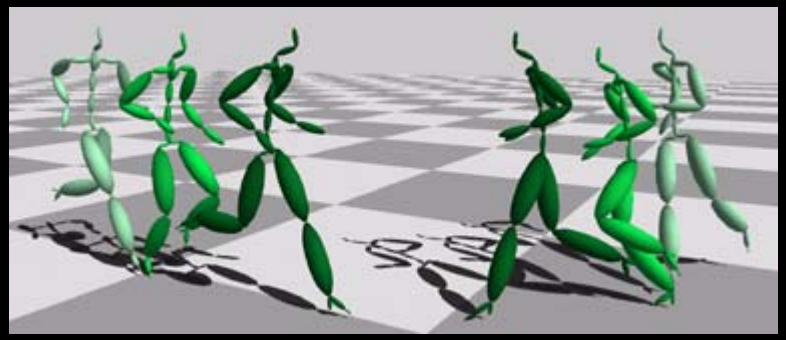
What is Similar?

Factor out invariances and measure

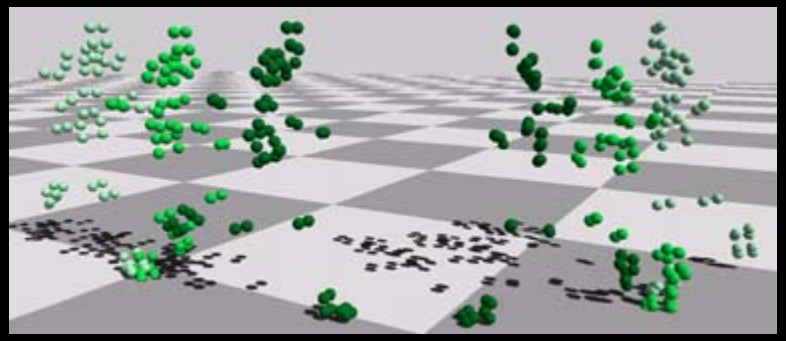
1) Initial frames



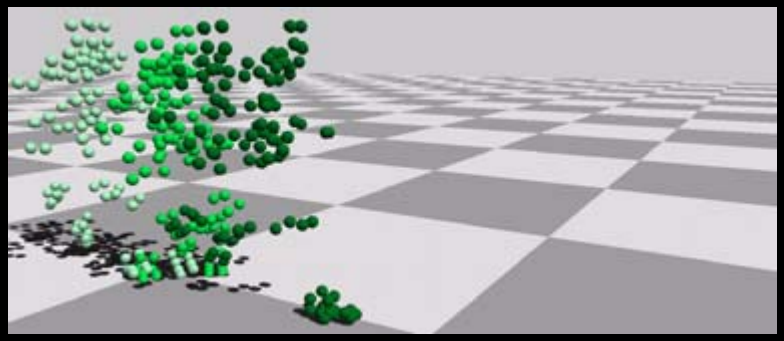
2) Extract windows



3) Convert to point clouds



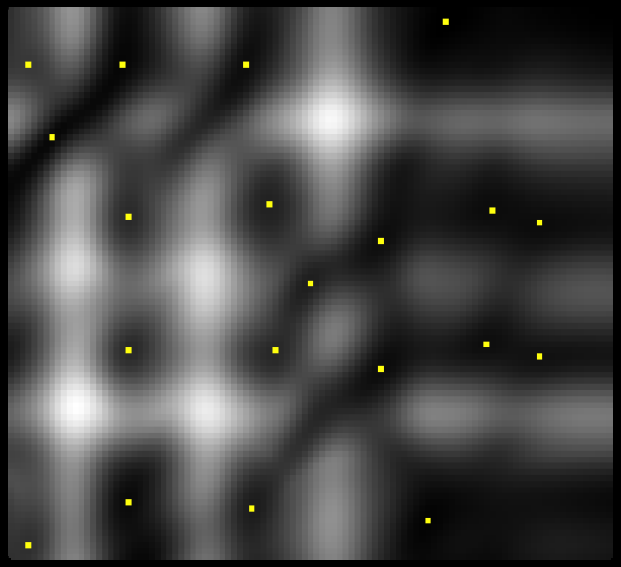
4) Align point clouds and sum squared distances



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

Finding Transition Points

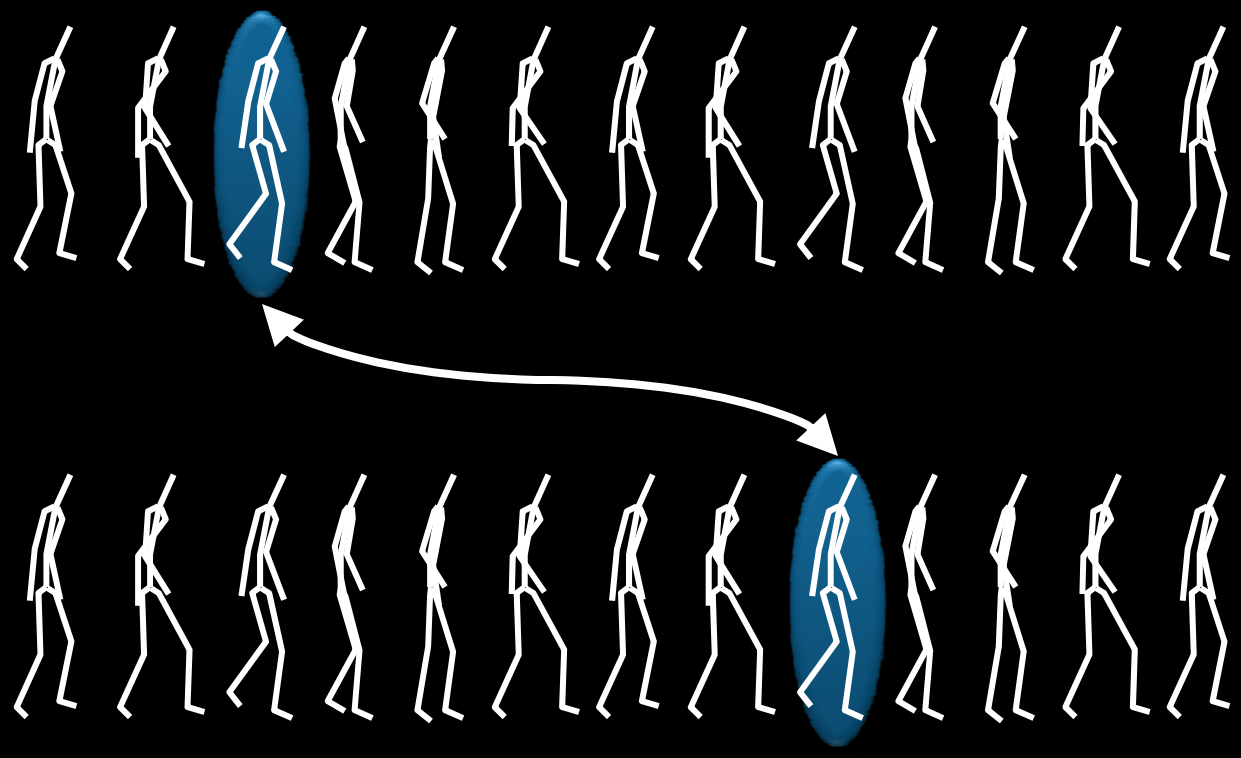
Every pair of frames now has a distance.



Transitions are local minima below a threshold.

Building a Motion Graph

- Find Matching States in Motions

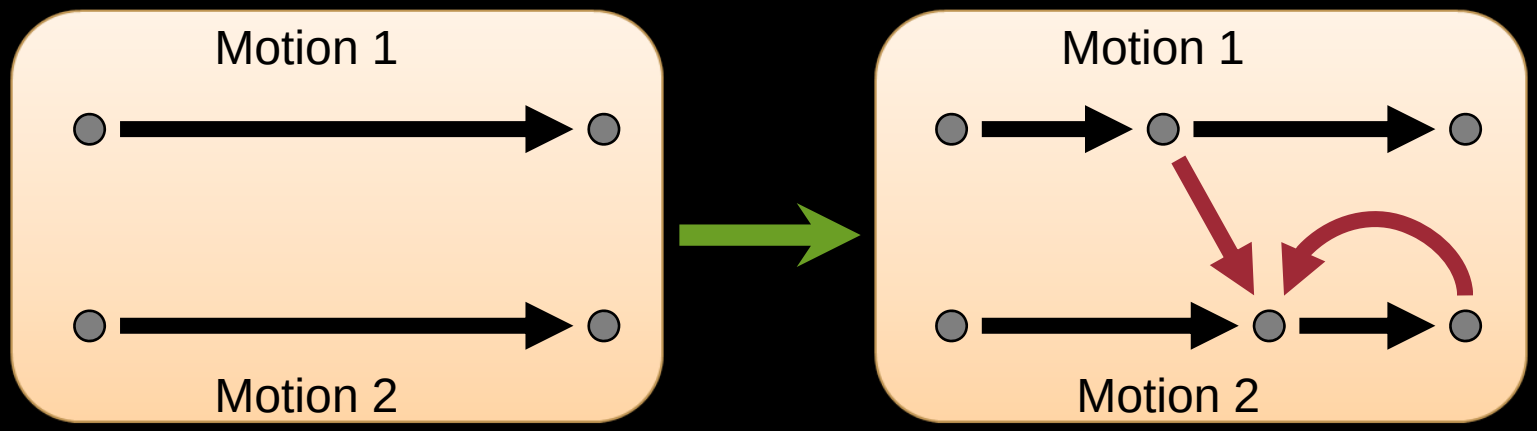


Motion Graphs

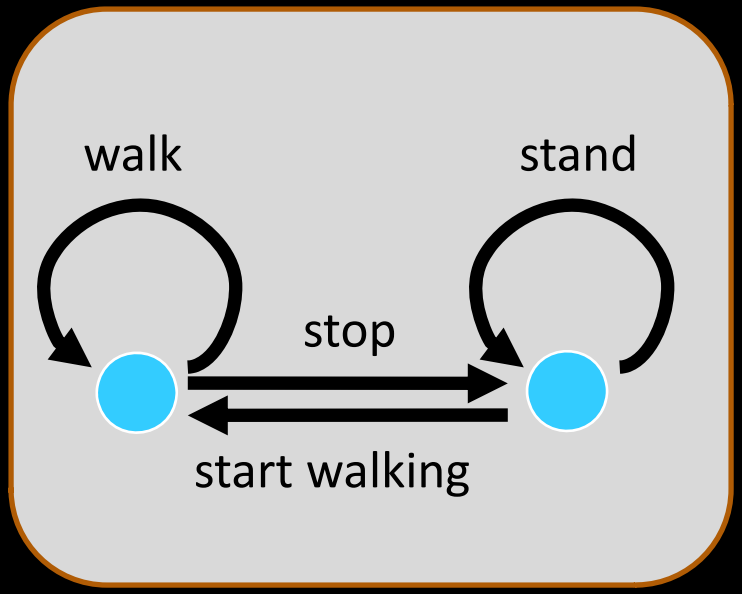
Kovar et al, Arikan&Forsyth, Lee et al. – All SIGGRAPH 02 and many other variants since

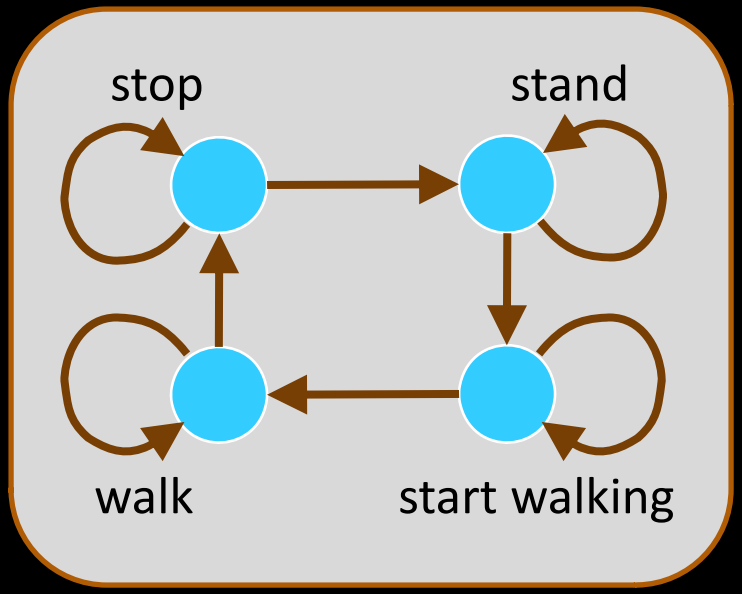
Start with a database of motions

Goal: add transitions at opportune points.



Graph Notation





Edge = clip

Node = choice point

Graph walk = motion

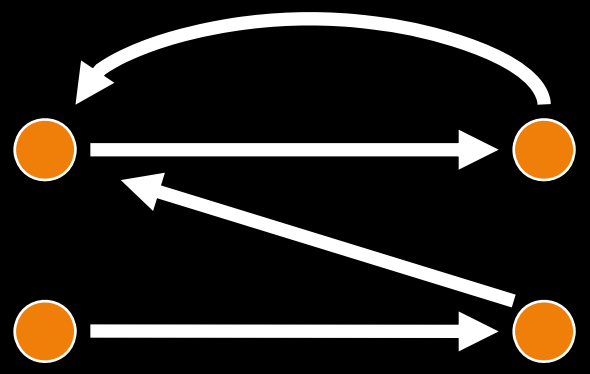
Edge = valid transition

Node = clip

Graph walk = motion

Motion Graphs

Idea: automatically add transitions within a motion database



Edge = clip

Node = choice point

Walk = motion

Quality: restrict transitions

Control: build walks that meet constraints

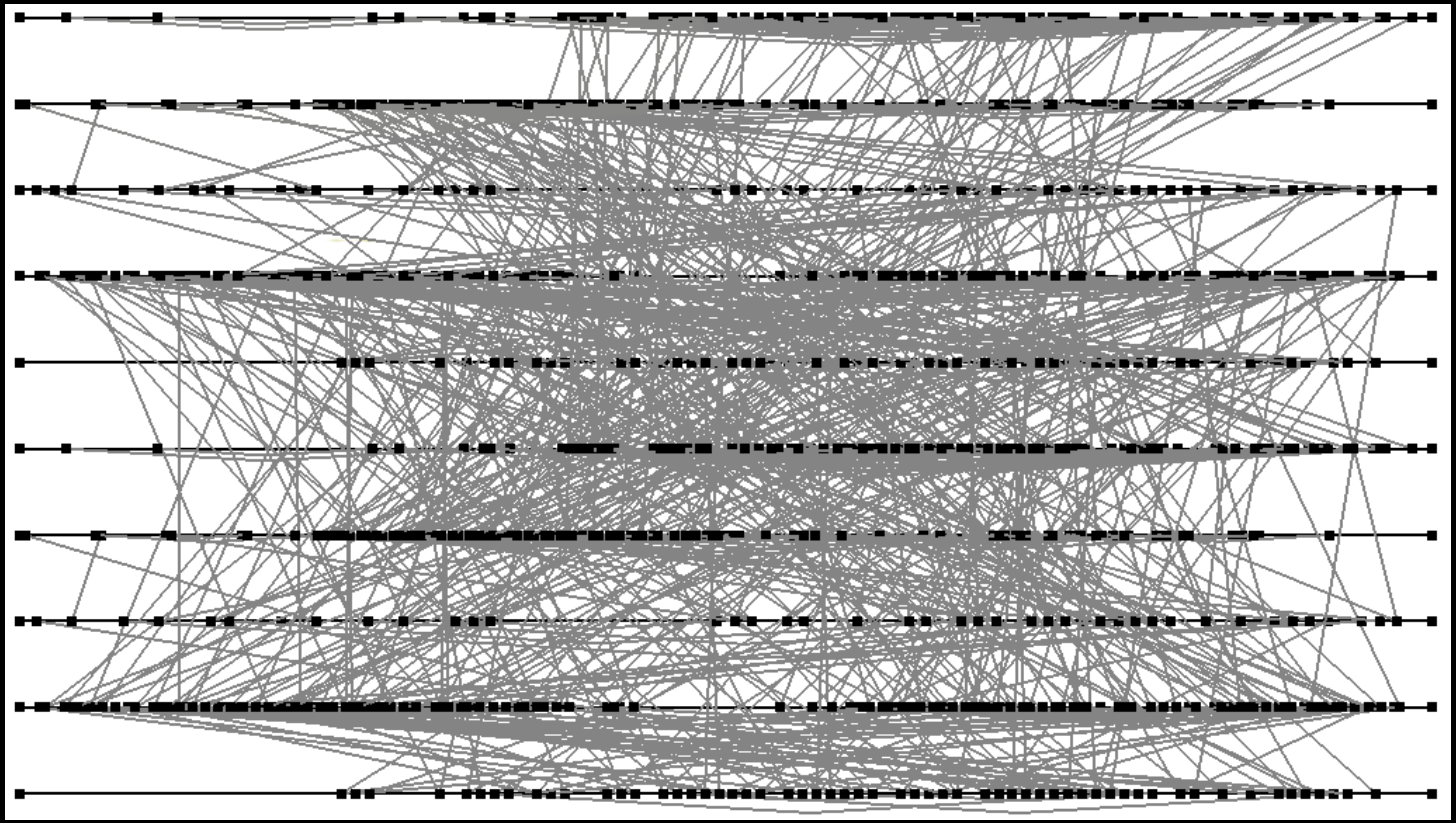
Using a motion graph

Any walk on the graph is a valid motion

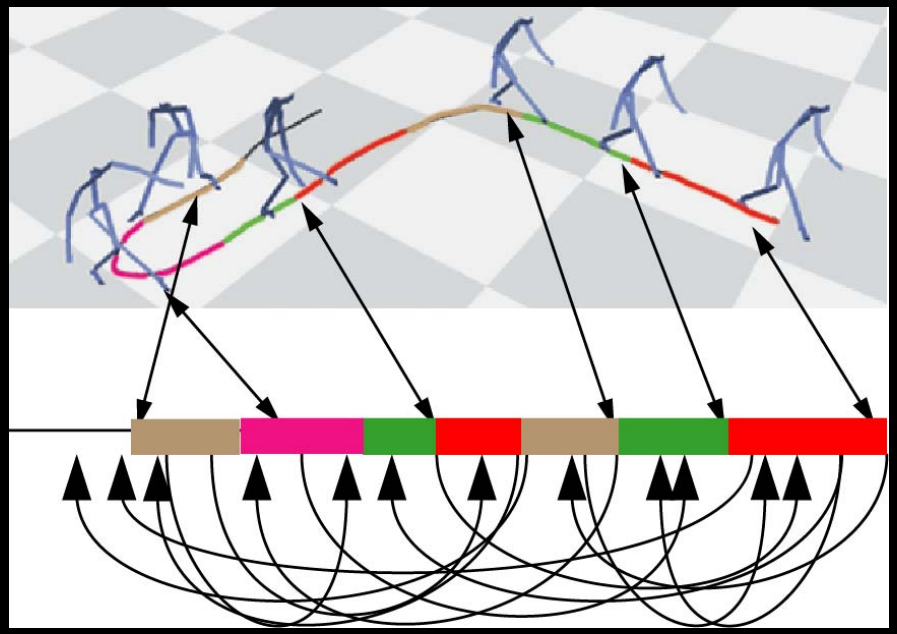
- Generate walks to meet goals
  - Random walks (screen savers)
  - Interactive control – pick an appropriate choice
  - Search to meet constraints
- There are many ways to use the graphs

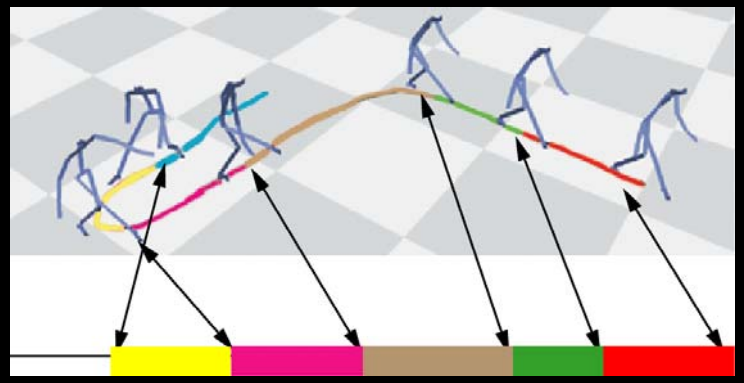
Structure of Motion Graphs

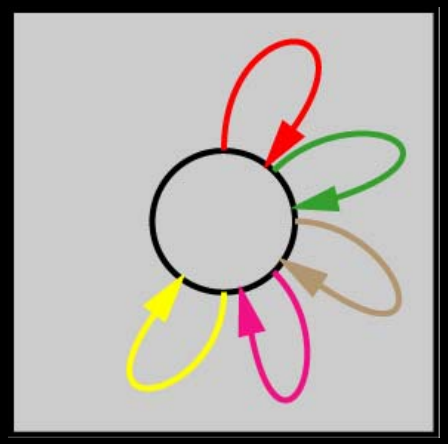
Opportunistically built graphs can be hard to search – especially for quick control



Structured vs. Unstructured Graphs



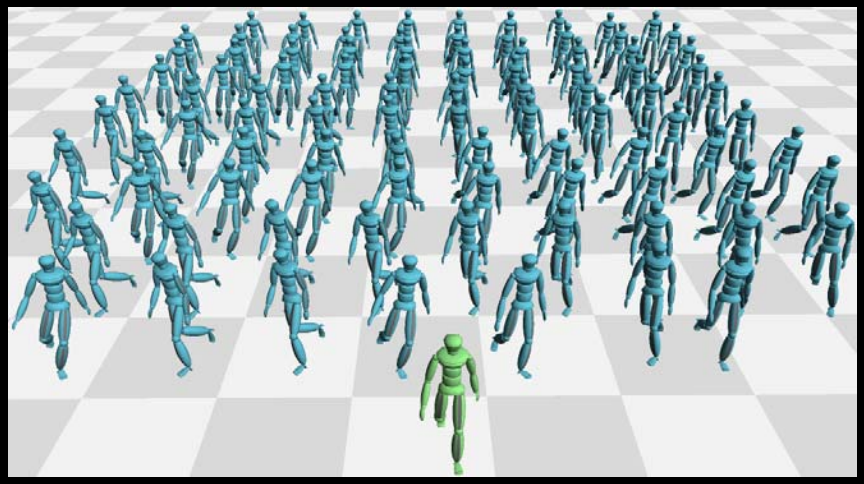


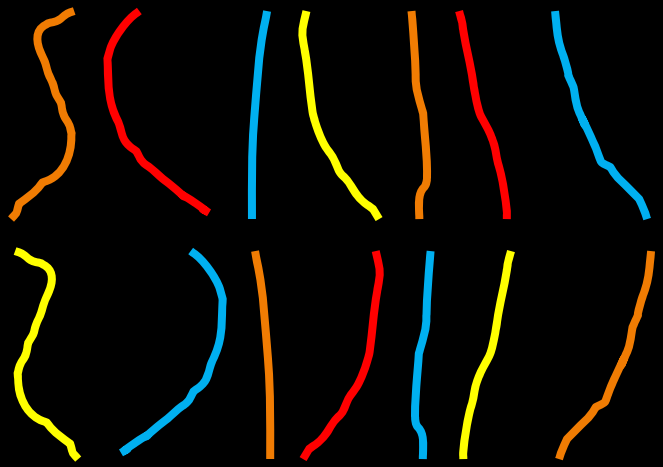


Gleicher et al. I3D 2003

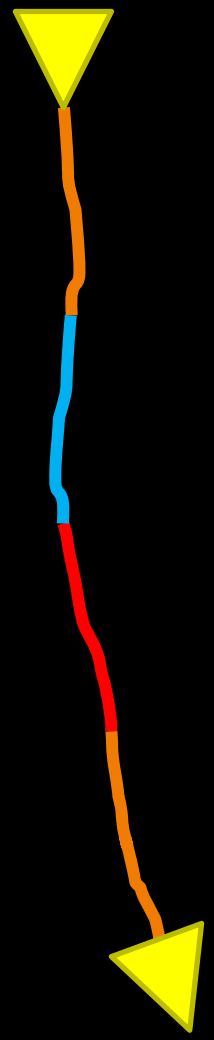
Search to goal

Search for a walk on the graph (sequence of clips) that meets the goals



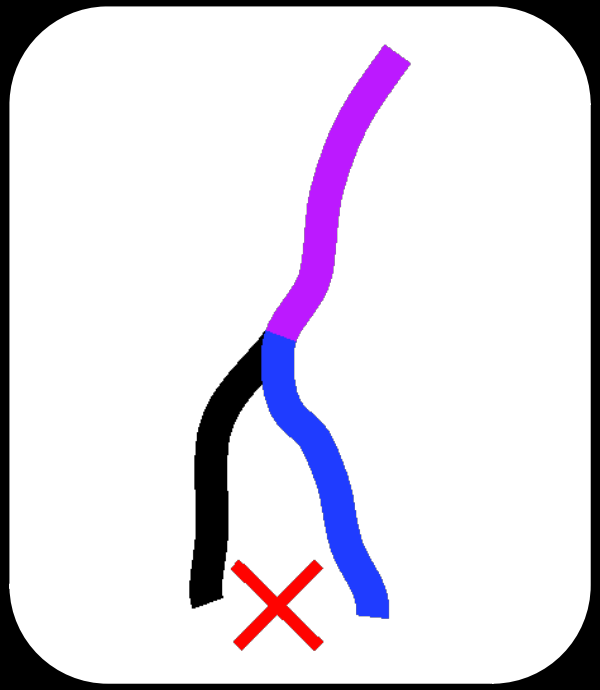


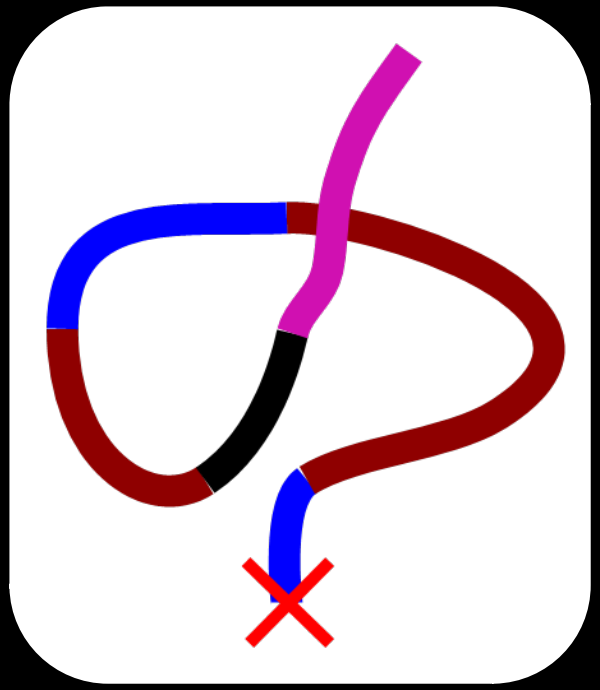
Search to a Goal



- Use your favorite discrete search
- Planning-like problem

Path Quality Tradeoffs





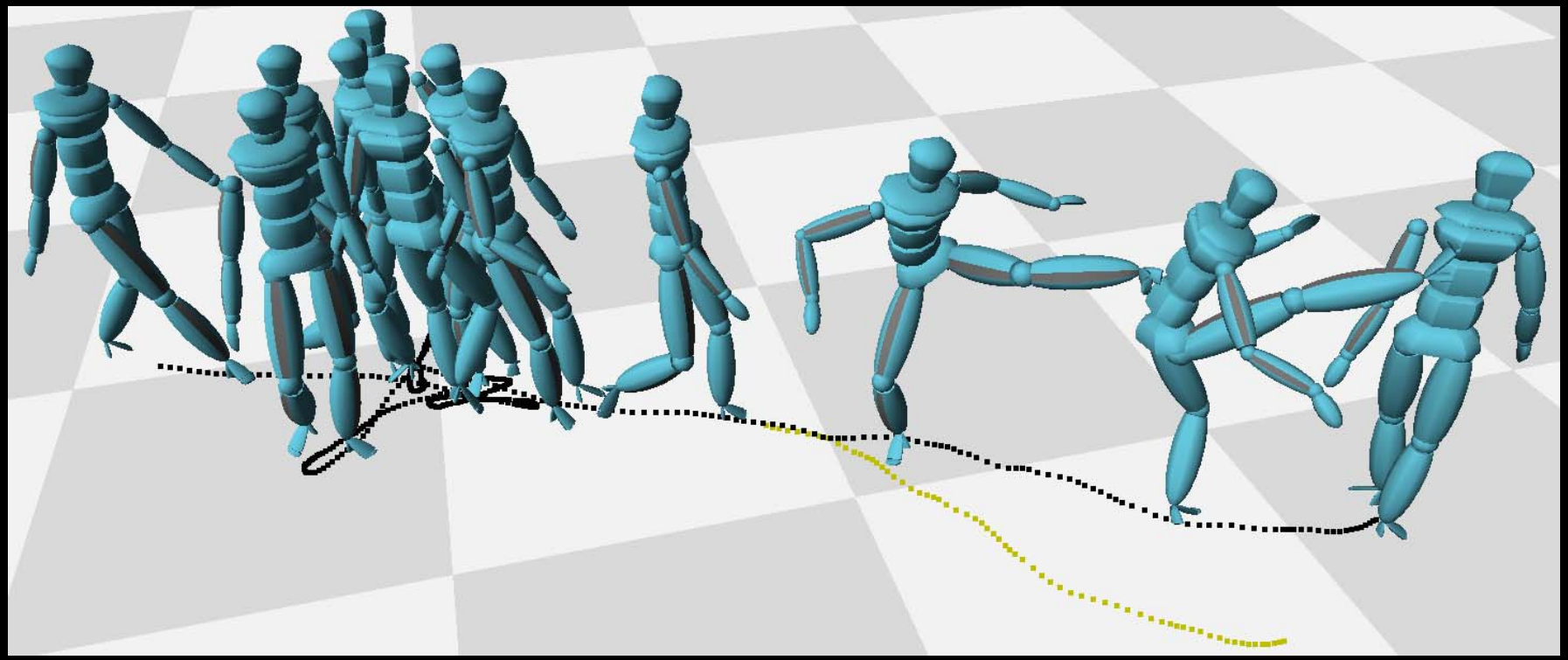
Discrete choices:

Can’t get exactly to goals

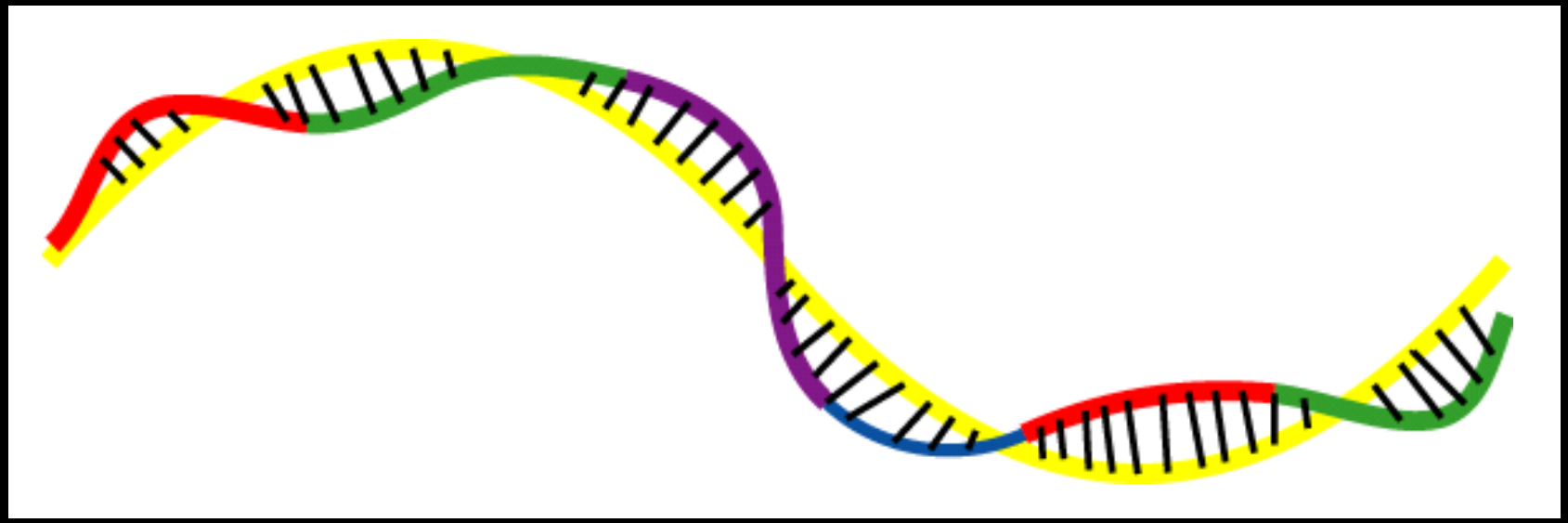
Discrete choices:

Closest fit might not be a good path

Bad paths happen



Path following works better



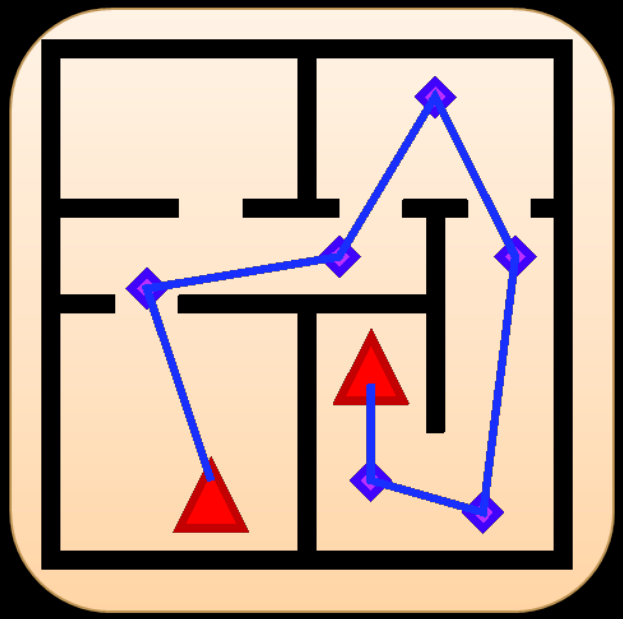
Multi-Level Solutions

Different methods for different aspects

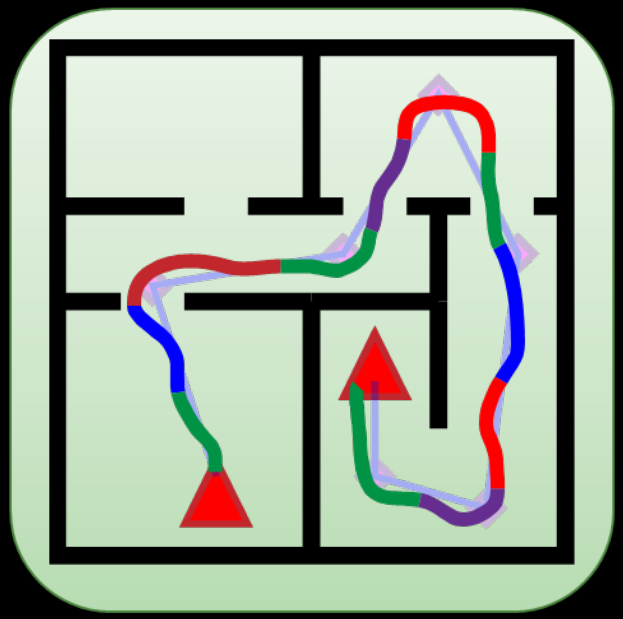
- Motion planning to get rough path
- Motion synthesis to follow path
  - Possibly only gets close
- Motion Adjustment to exactly meet goals

Example Multi-Level Solution

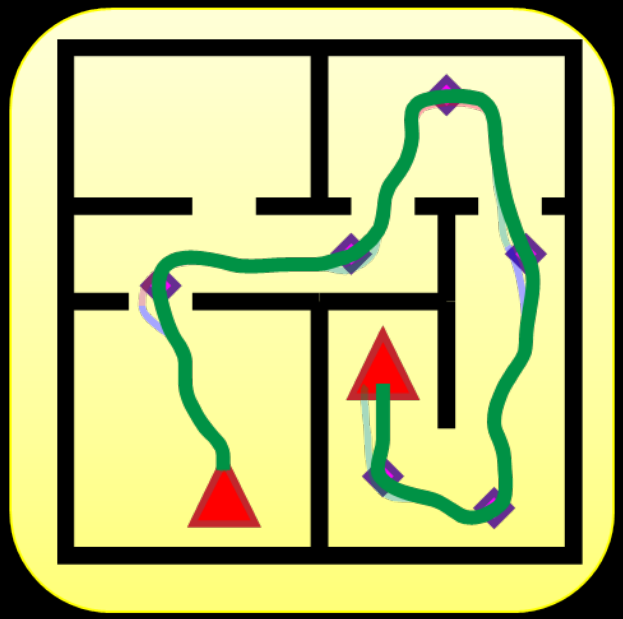
Sung, Kovar, Gleicher SCA 05



Motion Planning:
PRM-based



Motion Synthesis:
Greedy search of structured graph

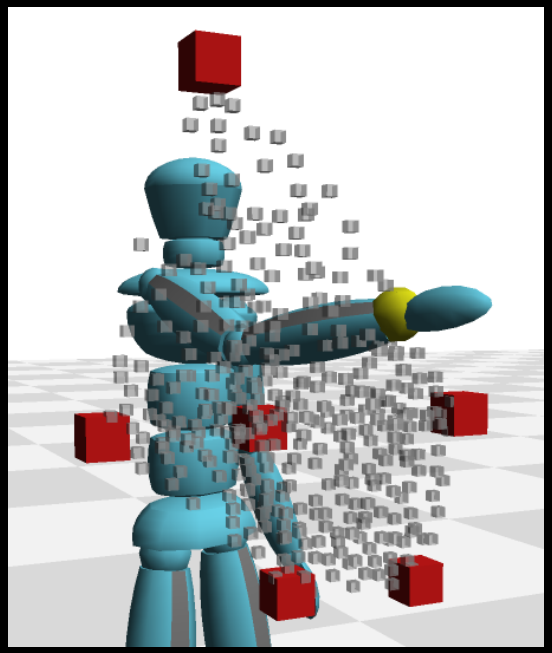


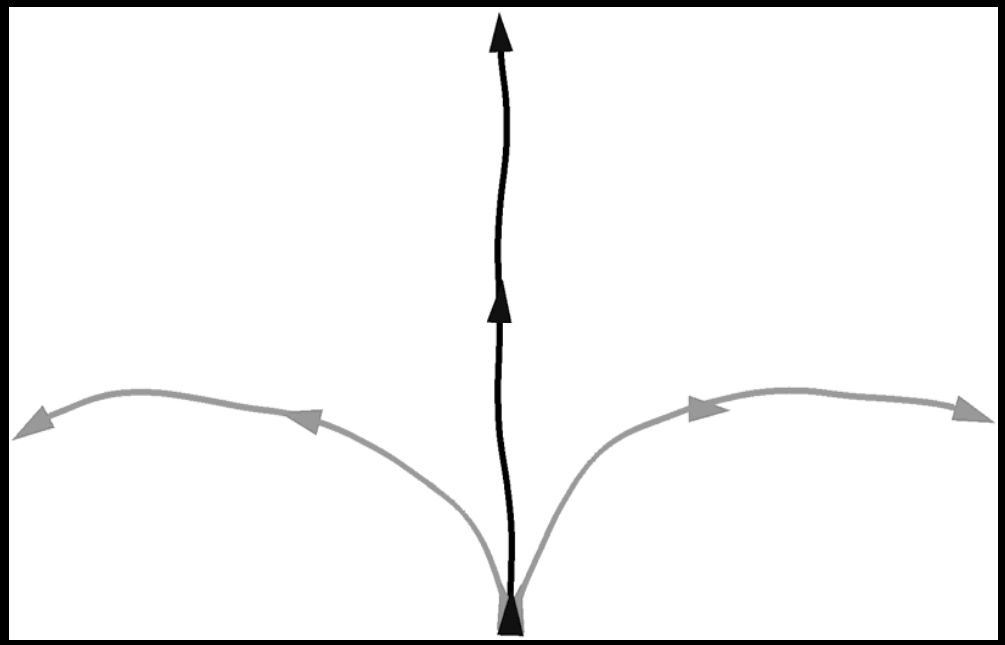
Fine Adjustment:
Distribute error

Continuous Control: Blending

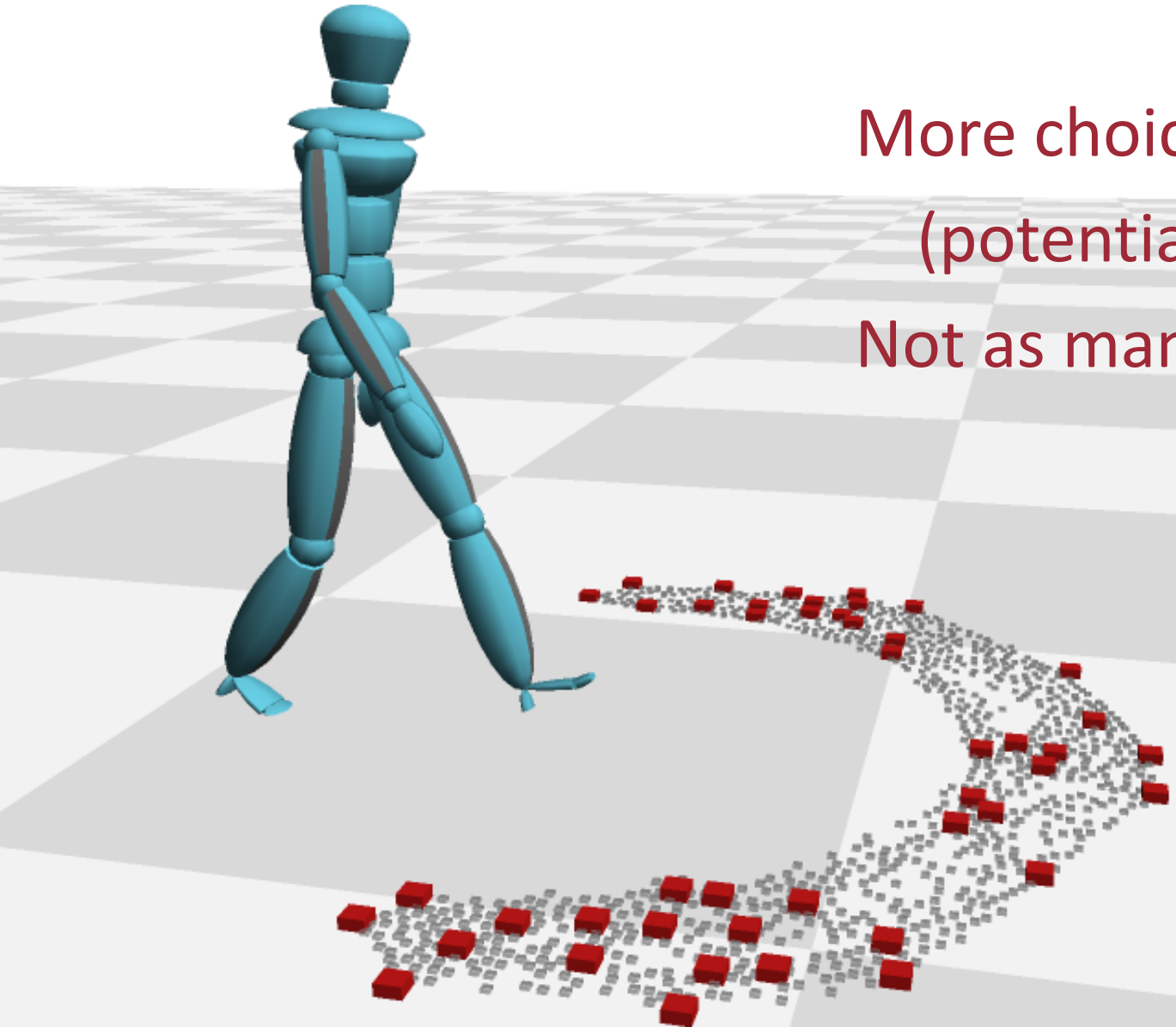
Range of motions by blending examples

- Get Motions “in-between” examples
- Allows for precise control





The advantages of blending



More choices!

(potentially infinite)

Not as many examples

From Kovar&Gleicher
SIGGRAPH '04

Parametric Graphs

Shin&Oh SCA06, Heck&Gleicher SI3D07, Safanova&Hodgins S07

- Graph of parts with blending
- Clips blended to get precise control

- Flexible synthesis and precision

- Considerable complexity
- Mixed discrete-continuous optimization

Review

Human motion at various level of detail

- Human Movement is Complex
  - Capture it (rather than model it)
- Synthesis By Example
  - Simple mechanisms for combining clips
  - Preparation to find where simple tools work
  - Control through choices
- Higher level “planning” to get rough paths
- Hybrid systems for navigation and synthesis

Summary

You can create detailed character movement that meets high-level goals

Key Idea:

Use methods appropriate for the levels of abstraction

- Motion planning to consider the high-level goals
- Motion Synthesis to create the movement details