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

Orientation
Position
Target
Time
duration
Initial

Synthesis

Planning
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

**Off-line Pre-process**
- Database
- Examples

**Run-time synthesis**
- Adjust
- Blend
- Sequence

**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, ...)

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- Adjust
- Blend
- Sequence
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 ...

+  +  +
Transitions

Some transitions are easy

Some transitions are hard
Simple Transition Methods

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

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