Robotics and Animatronics in Disney

Lecture 5: Adapting Human Motion Data to Different Kinematics

Katsu Yamane
kyamane@disneyresearch.com

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Goals

- Introduce a technique for mapping human motions to non-humanoid characters
- Introduce a technique for adapting human motions to different environmental constraints
- Discuss what features must be preserved to maintain naturalness

Extending the Horizon

- Subject and environment specific
  - Characters/robots with different mass properties?
- Mostly human subjects
  - Non-humanoid characters?
- Specific to environment
  - Different environment?

Animating Non-Humanoid Characters

[Yamane, Ariki, Hodgins 2010]

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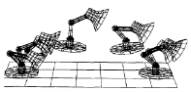
Animating Non-Humanoid Characters

Non-humanoid characters

Optimization: can't incorporate styles
Keyframing: rely on animator's talent



[Witkin and Kass 1988]

Our Approach

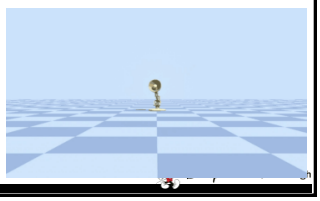
Use human motion capture data: leverage actor's talent
- Perform natural and expressive motions
- Imagine and imitate character's motion style

Challenge: mapping human motion to characters
- Nonlinear
- Small training data set

Example: Happy Lamp

human motion
in the character's style

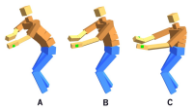
output of the system



Related Work

Motion retargeting

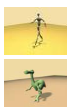
- Assume same topology [Choi and Ko 2000] [Mozani et al. 2000] [Shin et al. 2001] [Tak and Ko 2005]



Related Work

Motion retargeting for different topologies

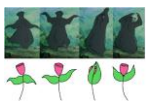
- Soda can example in [Gleicher 1998]: explicitly specify corresponding body parts
- Linear blending [Park and Shin 2004]
- Retargeting to user-created models [Hecker et al. 2008]: requires extensive annotation on the motions
- Retargeting mesh deformations [Baran et al. 2009]



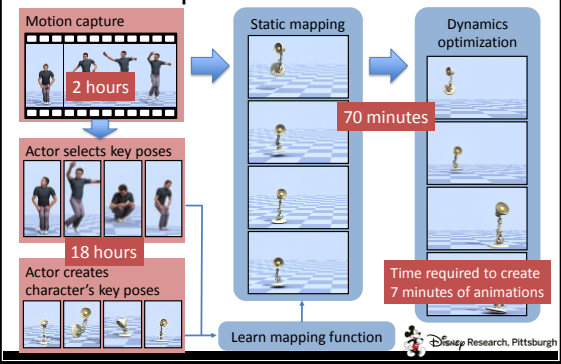
Related Work

Learning from artists' input

- Style transfer [Ikemoto et al. 2009]: requires example animations for the new character
- Transfer cartoon styles [Bregler et al. 2002]: primarily for 2D transformations



Pipeline Overview



Features

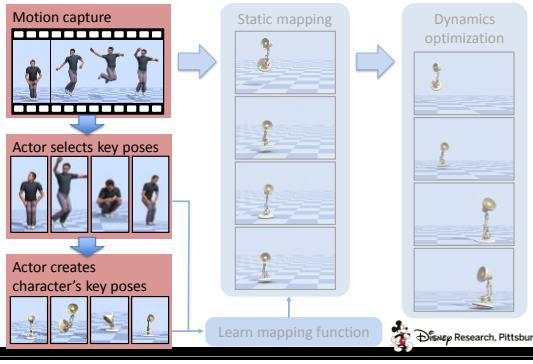
Sparse key poses (average interval 4.0s)

- Faster than complete keyframing

Leverage actor's talent

- Recorded motion: style, naturalness and expressiveness
- Key poses: body correspondence

Manual Tasks



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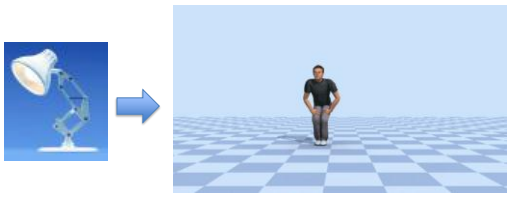
Motion Capture

Act in the character's style



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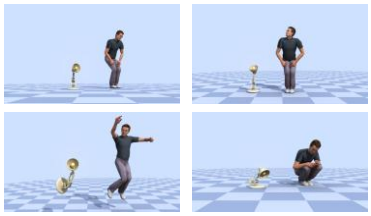
Key Pose Selection/Creation

Sparse but diverse set of key poses

Implicitly define the pose correspondence



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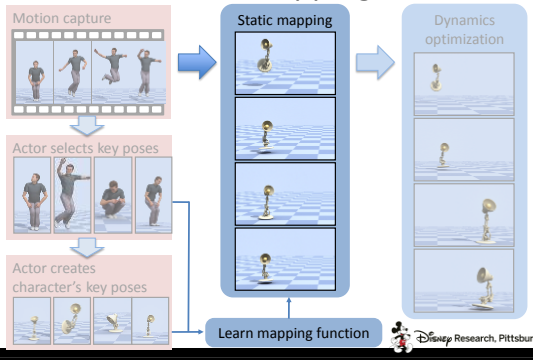
Static Mapping



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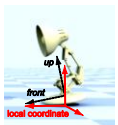
Static Mapping

Motion representation: trajectories of feature points in Cartesian coordinates [Arikan 2006]

- Human model: motion capture markers
- Character model: virtual markers (3 on each link)

Invariant to horizontal movements

- Feature point positions in the local coordinate



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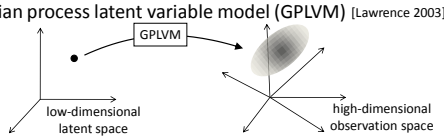
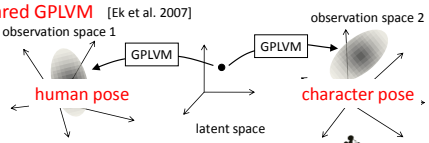
Static Mapping

Gaussian process latent variable model (GPLVM) [Lawrence 2003]



Shared GPLVM [Ek et al. 2007]



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Why Shared GPLVM?

Gaussian process

Sparse training data set

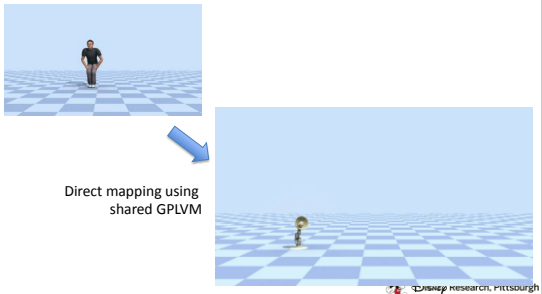
Latent variables

Human motions are confined to a low-dimensional space [Safonova et al. 2004]

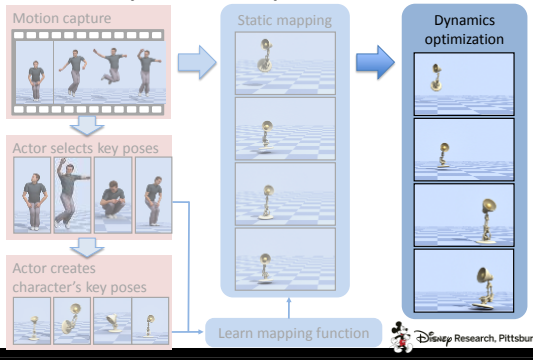
Shared

Common structure in human and character motions

Static Mapping



Dynamics Optimization



Dynamics Optimization

Horizontal movement

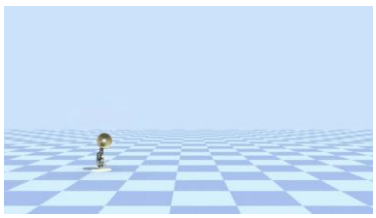
Contacts

Physical plausibility

Horizontal Movement

removed in static mapping

match linear and angular momenta to human motion



Contacts / Physical Plausibility

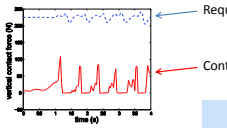
Contacts

- Correct contact points based on contact information of the original human motion and recalculate IK

Physical plausibility

- Modify joint trajectories so that required and actual contact forces match
- Penalty-based model for contact force computation
- Typically vertical translation only

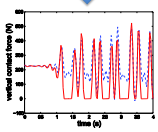
Contacts / Physical Plausibility

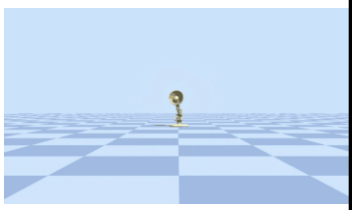


Required contact force from motion

Contact force from contact model

Contact point adjustment only





After improving physical plausibility

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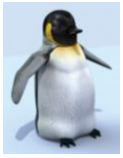
Results: Characters



Lamp	Penguin	Squirrel
• Topology • Hop instead of walk	• Short limbs • Locomotion style	• Relatively human-like • Walk on four legs

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Results: Data

motion	lamp		penguin		squirrel	
	length	key poses	length	key poses	length	key poses
anger	18.6	16	14.3	3	22.9	14
disgust	34.4	1	23.3	7	20.0	3
fear	29.7	2	25.2	4	28.5	18
happiness	20.1	7	23.7	11	25.8	9
sadness	19.5	3	29.6	4	26.7	3
surprise	10.7	1	26.1	4	19.2	5
dance	14.7	0	25.6	0	26.1	6
total	148	30	168	33	169	58

Motion length (s)/number of key poses

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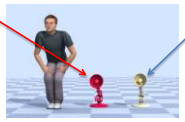
Results: Comparisons

Gaussian process

human pose

↓

character pose



shared GPLVM

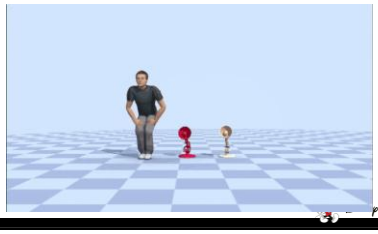
human pose

↓

latent space

↓

character pose



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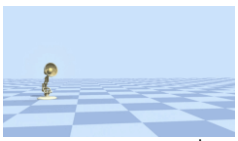
Results: Emotional Motions

anger / disgust / fear / happiness / sadness / surprise

anger

disgust



sadness

fear

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Results: Dances

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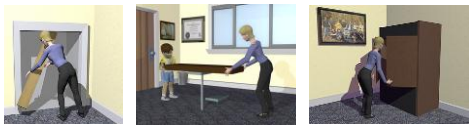
Contributions

New approach that leverages actor's talent
- Natural and expressive motions in the character's style
- Human-character pose correspondence
- Faster than keyframing

Techniques
- Shared GPLVM for mapping nonlinear pose spaces
- Physics-based optimization for fixing artifacts



Adapting to New Environments

[Yamane, Kuffner, Hodgins 2004]

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Constrained Motions

- Manipulating an object
- Opening a door / drawer
- Cooperative lifting

- Difficulty in synthesis
  - Hard constraints (hands, feet)
  - Object / body / environment collisions
  - Naturalness / style

Motivation

	Model-driven Simulate kinematics / dynamics model	Data-driven Connect postures from a database
Good	Physically correct Easy to include constraints	Natural
Bad	Difficult to obtain natural motions	Difficult to handle new scenario

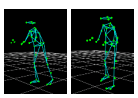
Insight: combine the two approaches

Our Approach

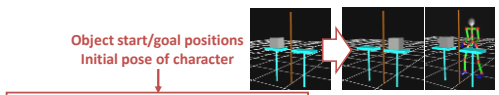
Focus on constrained, collision-free motions

- Use model for flexibility
  - IK: constraints, balance, different characters
  - Planning: environment, different geometry

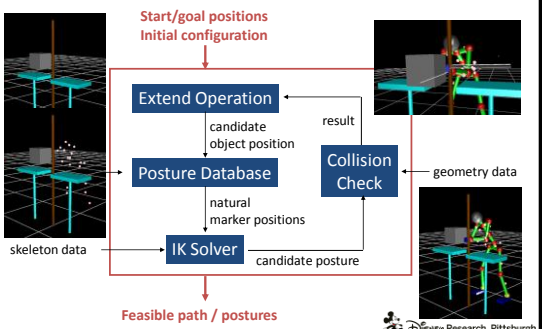
- Use data for naturalness / style
  - Bias the IK solution toward natural postures
  - Different databases for different styles



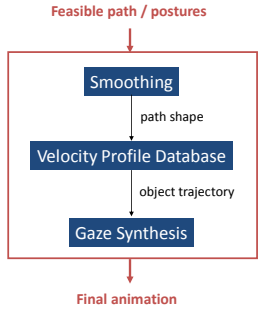
System Overview



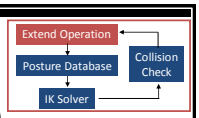
System Overview: Planning



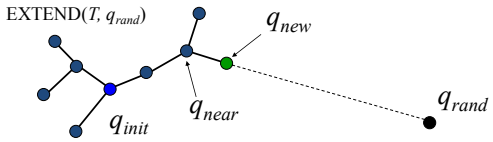
System Overview: Post-Processing



Extend Operation

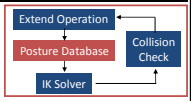


- RRT (Rapidly-exploring Random Trees)
  [Kuffner and LaValle, 2000]

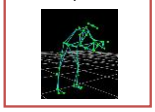


- Plan in object space and compute IK for each node
  - Fast planning
  - Full collision detection

Posture Database

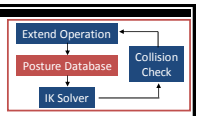


- Gives natural posture for each node
- Joint angles vs. marker positions



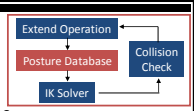
- Advantages
  - Applicable to any skeleton (DOF, limb length)
  - Easier data processing (3D reconstruction + labeling)

Posture Database

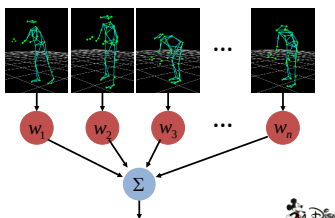


- Database entries
  - Extract frames from several two-arm manipulations of a box
  - Remove similar postures
  - Frame-to-frame coherency not stored

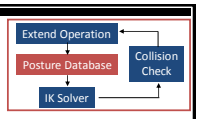
Natural Marker Positions



- Simple linear combination of all entries
- Adjust the weights to match the hand / feet positions given by the planner



Computing the Weights



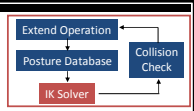
- Linear equation
- Pseudoinverse can be precomputed

$$\begin{pmatrix} c^1_{lhand} & c^2_{lhand} & \cdots & c^{nf}_{lhand} \\ c^1_{rhand} & c^2_{rhand} & \cdots & c^{nf}_{rhand} \\ c^1_{lfoot} & c^2_{lfoot} & \cdots & c^{nf}_{lfoot} \\ c^1_{rfoot} & c^2_{rfoot} & \cdots & c^{nf}_{rfoot} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_{nf} \end{pmatrix} = \begin{pmatrix} p_{lhand} \\ p_{rhand} \\ p_{lfoot} \\ p_{rfoot} \end{pmatrix}$$

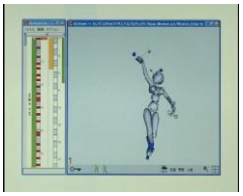
database entries (→) ; constraints (↓)

Hand/foot positions in the database | Weights | Hand/foot positions specified by the planner

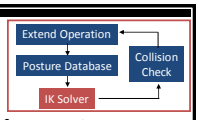
IK Solver



- UTPoser
  - Flexible inverse kinematics (IK) [Yamane and Nakamura 2003]
  - Intuitive pin-and-drag interface
- Two priority levels
  - Higher: dragged link
  - Lower: pinned links
- Problem: redundancy
  - Selects one numerically stable solution for IK problem
  - Not always natural



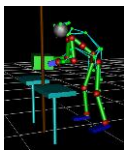
IK Solver



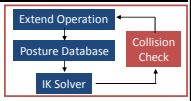
- Use the natural marker positions as soft constraints to bias the IK solution

Minimize $\Sigma\|p_m - p_m^{ref}\|^2 + \|p_{com} - p_{com}^{ref}\|^2$ subject to $\Sigma\|p_h - p_h^{ref}\|^2 = 0$

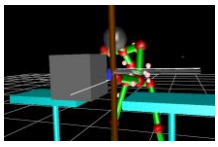
- Simple interpolation of database entries is enough because
  - IK takes care of the hard constraints
  - Database entries and constraints are of the same dimension
- Generalizes a database for wider range of tasks, character, environment



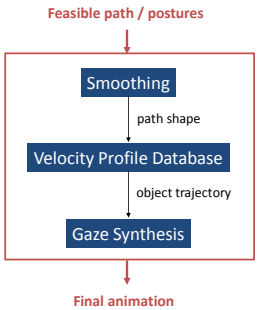
Collision Check



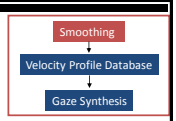
- External collision detection library
  - ColDet (http://photoneffect.com/coldet/)



Details: Post-Processing

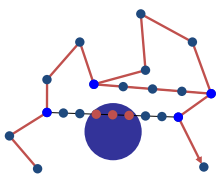


Smoothing

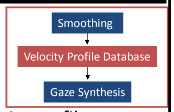


Optimize the path

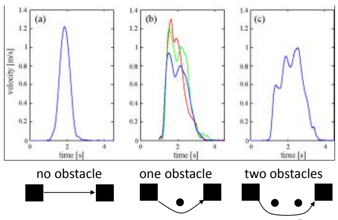
1. Select two arbitrary nodes on the planned path
2. Connect the two nodes
3. Solve IK on the new path and check collisions



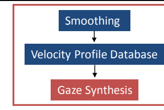
Velocity Profile



Observation: similar paths have similar velocity profiles [Atkeson and Hollerbach 1985]



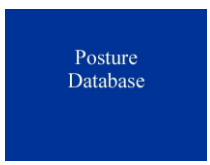
Gaze Synthesis



- IK with gaze direction constraints
- Target direction given by the user
  e.g. object goal position

Results

- Posture database
  - 247 frames from four motions
- Velocity profile database
  - 21 sets of path + velocity profiles
- Total time
  - Initial setup < 10 min. (in 3DCG software package)
  - Planning: 1~5 min. (depends on complexity of environment)
  - Post-processing: ~1 min.
- cf. 1-2 hours of keyframing in Maya by a trained user



Results

- Character
  - adult
  - child
  - long-legged clown
  - long-armed gorilla
- Environment
  - shelf
  - closet
  - car trunk
- Task
  - cooperative manipulation
  - opening a desk drawer
  - opening a cabinet
  - one-handed manipulation

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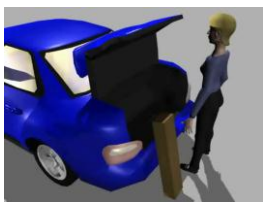

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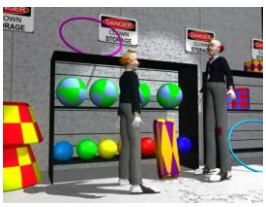

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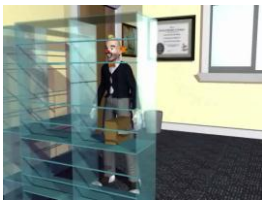


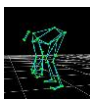
(with specialized database)

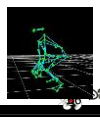
Results

Different styles for lifting with two different databases

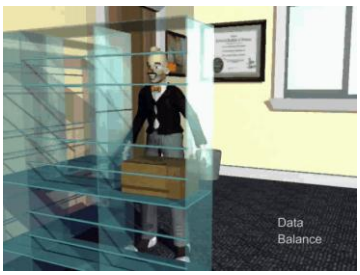
bend back

bend knee



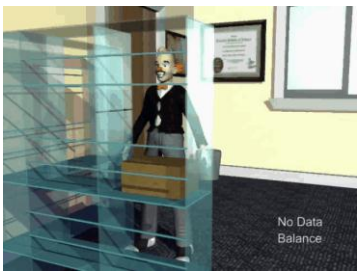


Evaluation: with/without Data



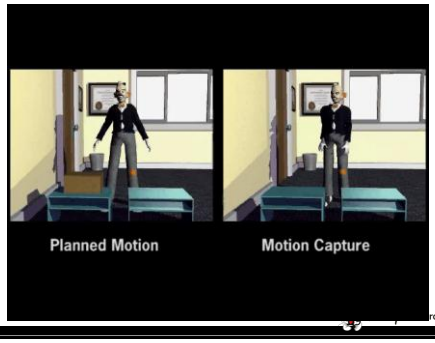
with data

Evaluation: with/without Data



without data

Comparison with Motion Capture



Conclusion

- Combination of model- and data-driven approaches for synthesizing constrained motions
  - With emphasis on the model (IK / planning)
- Model generalizes a single database to various
  - Characters
  - Environments
  - tasks
- Data supports the model by adding
  - Naturalness
  - Style

Discussions

- Significantly different character / environment
  - Large change required
- How much change is acceptable to
  - Maintain the style
  - Look natural