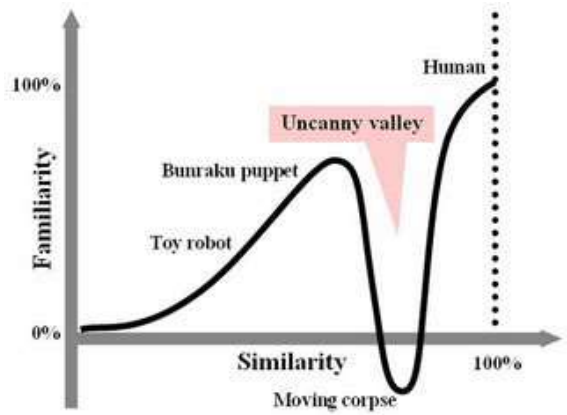
Animation & Simulation

He Wang (王鹤)

Modeling and Animating Human Figures

- Very formidable task
  - Too familiar (uncanny valley)



Modeling and Animating Human Figures

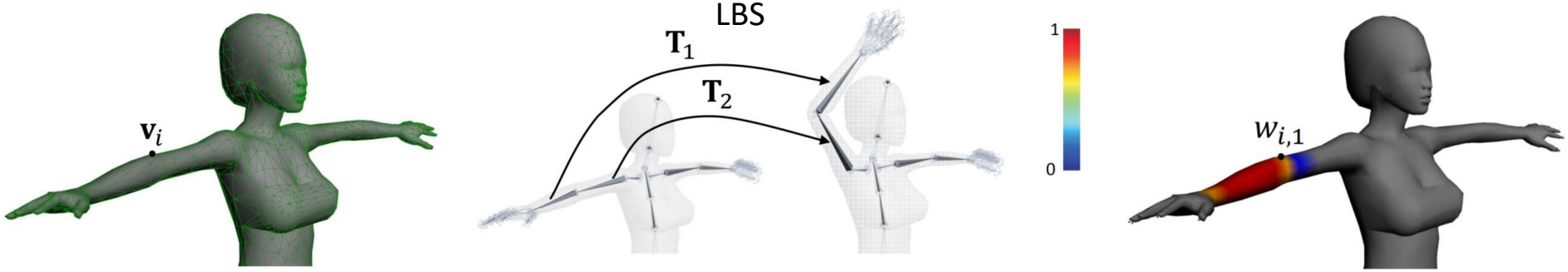
- Very formidable task
  - Too familiar (uncanny valley)
  - High Complexity
    - > 200 bones, > 600 muscles, approx. 200 Dofs, deformable skins
  - Human-like motion is not computationally defined
    - What makes a natural motion natural?
  - No definitive motion that is human-like
- Virtual human representation
  - Skins
  - Bones, muscles, tissues and fat
  - Hairs
  - Clothing

Modeling and Animating Human Figures

- Virtual human representation
  - Representing body geometry
    - Polygons (triangles) or Patches (non-uniform rational b-splines, NURBs)
    - Normally in off-shell modelling tools
    - If speed is important, polygons; otherwise patches

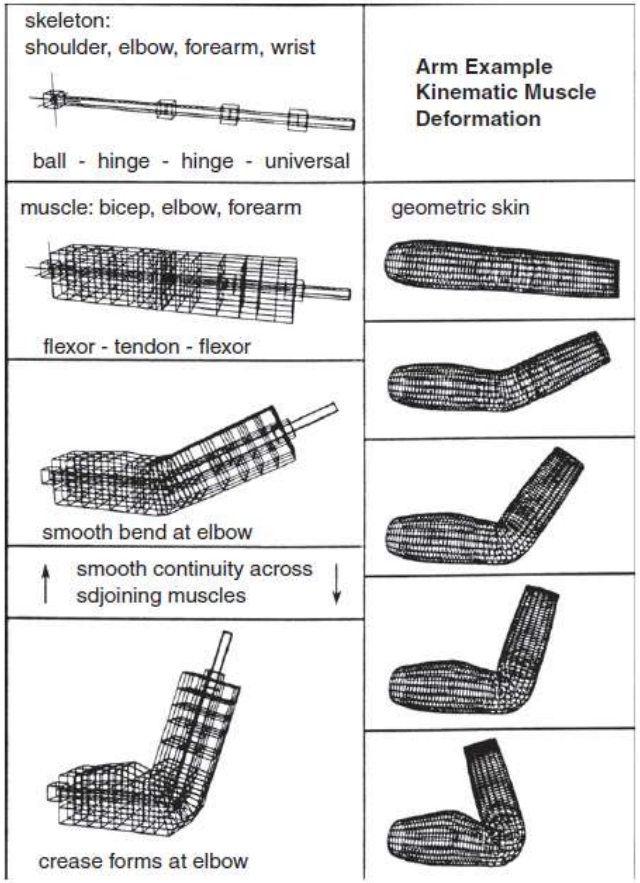
Modeling and Animating Human Figures

- Virtual human representation
  - Geometric Data Acquisition
    - Scanner, point clouds->patches->surfaces
    - Video images->surfaces (https://www.microsoft.com/en-us/mixed-reality/capture-studios)
  - Geometry deformation
    - Decomposed into multiple rigid body parts
    - A single mesh, FFD
    - More elaborate deformation->skinning, Linear Blending, Dual-quaternions, etc



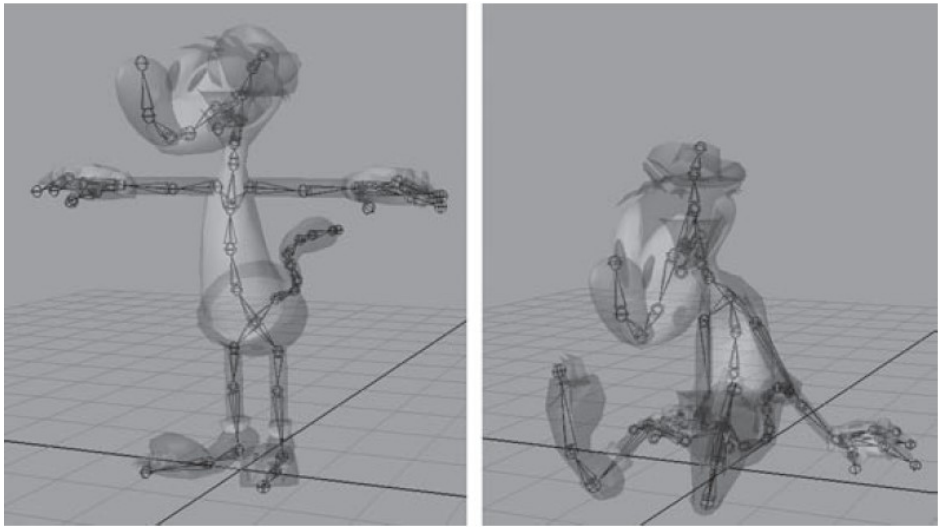
Modeling and Animating Human Figures

- Virtual human representation
  - Surface details (from artists)
  - Layered approach
    - Muscle layer + skin layer, coupled, two systems of FFD



Animation Systems (character)

- Animation Clips
  - Skinning



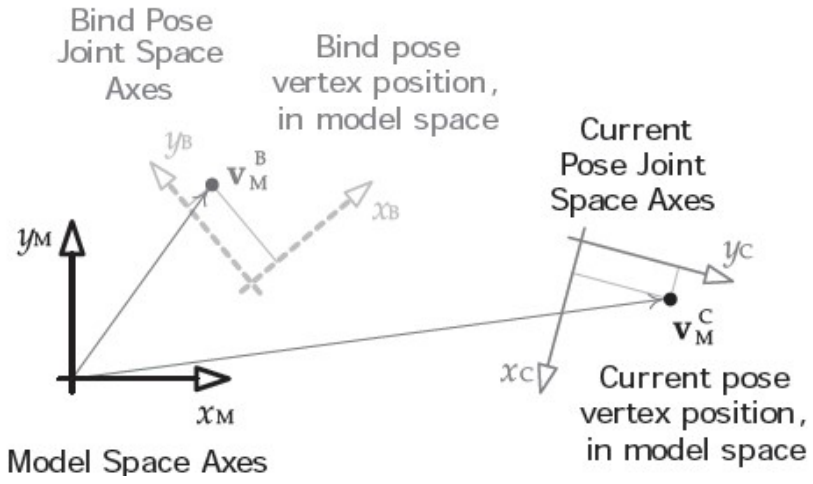
Animation Systems (character)

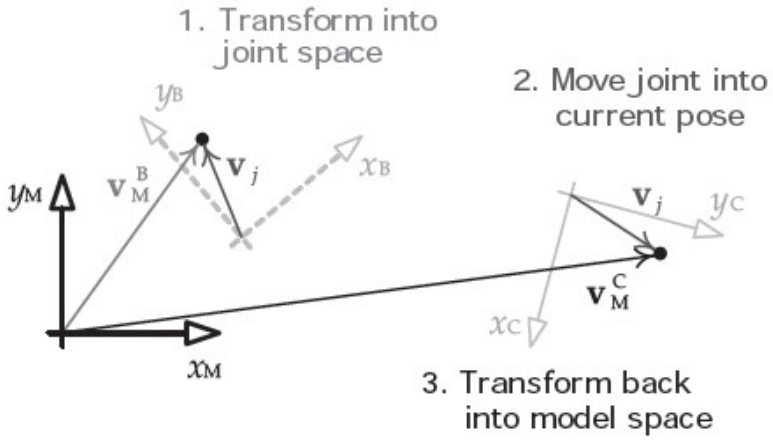
- Animation Clips
  - Skinning
    - Mesh vertex
      - A weighted combination of joints

```
struct SkinnedVertex
{
    float m_position[3];     // (Px, Py, Pz)

    float m_normal[3];       // (Nx, Ny, Nz)

    float m_u, m_v;          // texture coordinates
                             //    (u,v)

    U8    m_jointIndex[4];   // joint indices
    float m_jointWeight[3];  // joint weights, last one
                               //omitted
};
```

Animation Systems (character)

- Animation Clips
  - Skinning
    - Mesh vertex
      - One-joint skeleton





Animation Systems (character)

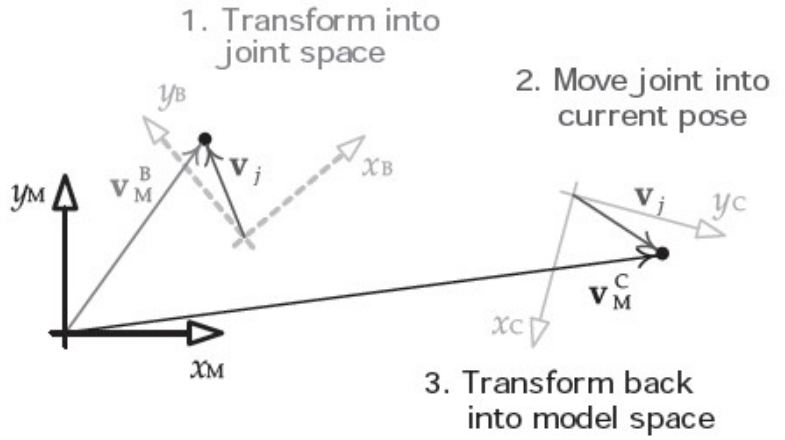
- Animation Clips
  - Skinning
    - Mesh vertex
      - One-joint skeleton

$$\mathbf{v}_j = \mathbf{v}_{\mathrm{M}}^{\mathrm{B}}\,\mathbf{B}_{\mathrm{M}\to j}$$

$$\mathbf{v}_{\mathrm{M}}^{\mathrm{C}} = \mathbf{v}_j\,\mathbf{C}_{j\to\mathrm{M}}$$

$$= \mathbf{v}_{\mathrm{M}}^{\mathrm{B}}\,(\mathbf{B}_{j\to\mathrm{M}})^{-1}\,\mathbf{C}_{j\to\mathrm{M}}$$

$$= \mathbf{v}_{\mathrm{M}}^{\mathrm{B}}\,\mathbf{K}_j.$$

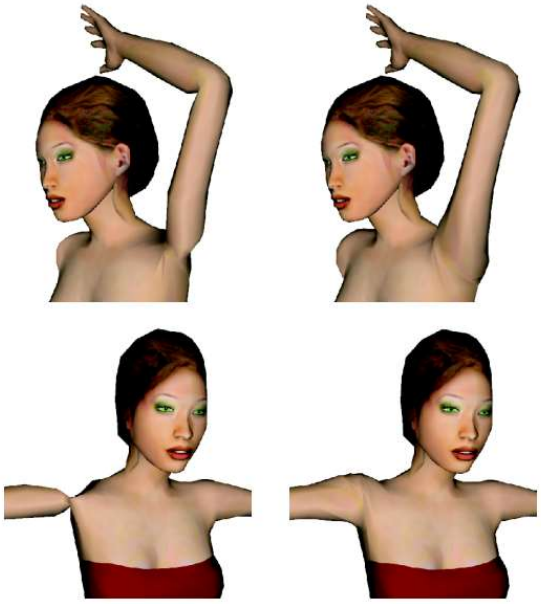


$\mathbf{K}_j = (\mathbf{B}_{j\to\mathrm{M}})^{-1}\mathbf{C}_{j\to\mathrm{M}}$ is known as a *skinning matrix*.

Animation Systems (character)

- Animation Clips
  - Skinning
    - Mesh vertex
      - One-joint extends to multiple joints: a weighted combination
      - Matrix pallete

$$\mathbf{v}_{\mathrm{M}}^{\mathrm{C}} = \sum_{i=0}^{N-1} w_{ij} \mathbf{v}_{\mathrm{M}}^{\mathrm{B}} \mathbf{K}_i$$



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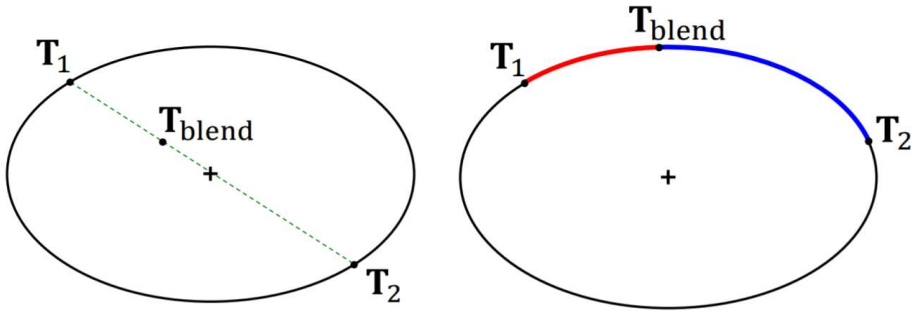
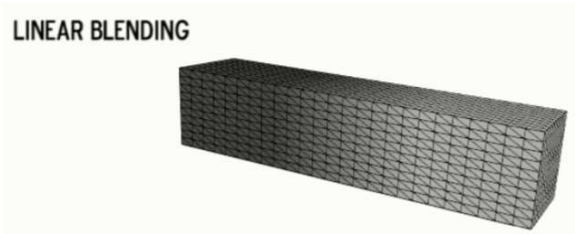
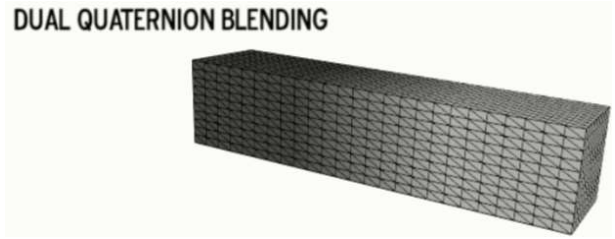
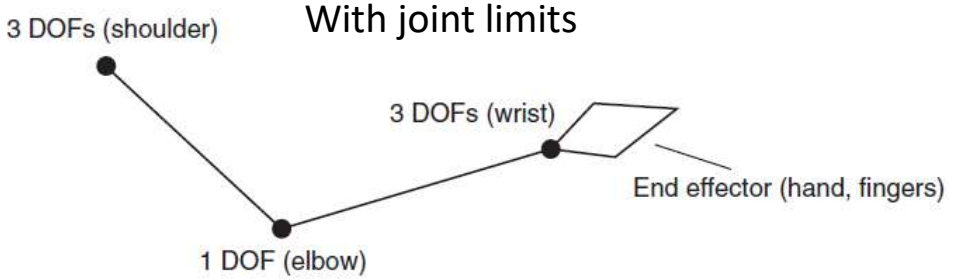






Modeling and Animating Human Figures

- Reaching and Grasping
  - Arm modelling
    - IK does not enforce joint limits
    - Even if enforced, still under-constrained
    - Can optimise so that the motion is smooth
      - How?
        - Compute intermediate postures or positions
        - Minimise velocity/acc change
        - Subject to valid joint ranges: a < joint < b
        - Quadratic Programming & Lagrangian Multiplier



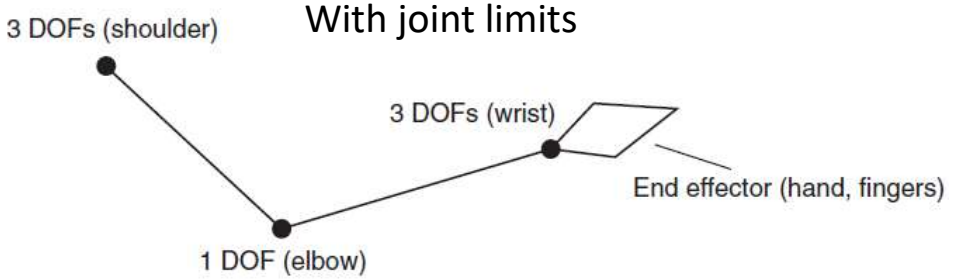
$$\begin{aligned} \text{minimize} \quad & \tfrac{1}{2}\mathbf{x}^{\mathrm{T}} Q\mathbf{x} + \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} \quad & A\mathbf{x} \preceq \mathbf{b}, \end{aligned}$$

Synthesis of Complex Dynamic Character Motion from Simple Animations, SIGGRAPH 2002.

An Energy-Driven Motion Planning Method for Two Distant Postures, IEEE TVCG 2015.

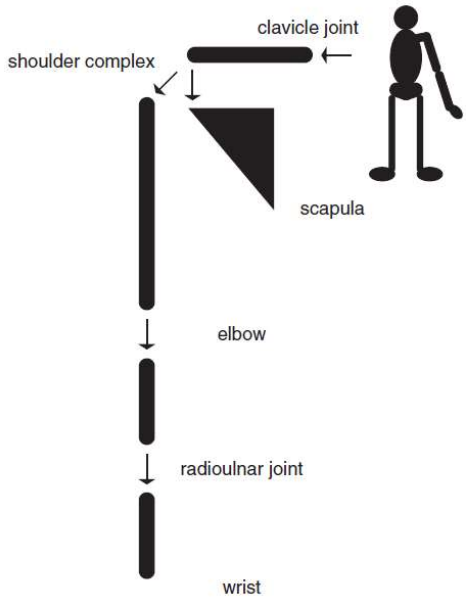
Modeling and Animating Human Figures

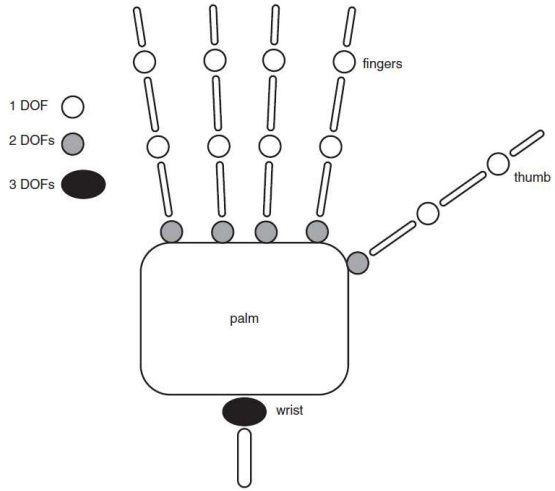
- Reaching and Grasping
  - Arm modelling
    - IK does not enforce joint limits
    - Even if enforced, still under-constrained
    - Can optimise so that the motion is smooth
    - Other factors: comfort, habit and styles, etc.



Modeling and Animating Human Figures

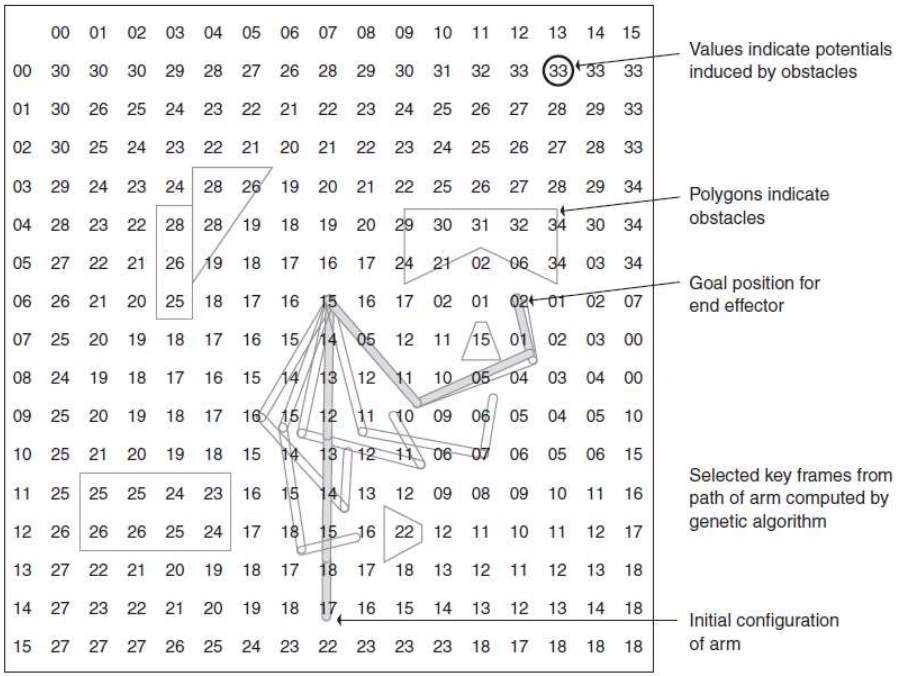
- Reaching and Grasping
  - Shoulder & Hand





Modeling and Animating Human Figures

- Reaching and Grasping
  - Coordinated motion
    - More Dofs involved, more difficult
  - Reaching around obstacles
    - Potential field



Modeling and Animating Human Figures

- Reaching and Grasping
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    - Potential field
    - Global path planning (Probabilistic roadmaps, PRMs, Rapidly-exploring random trees, RRTs)

Modeling and Animating Human Figures

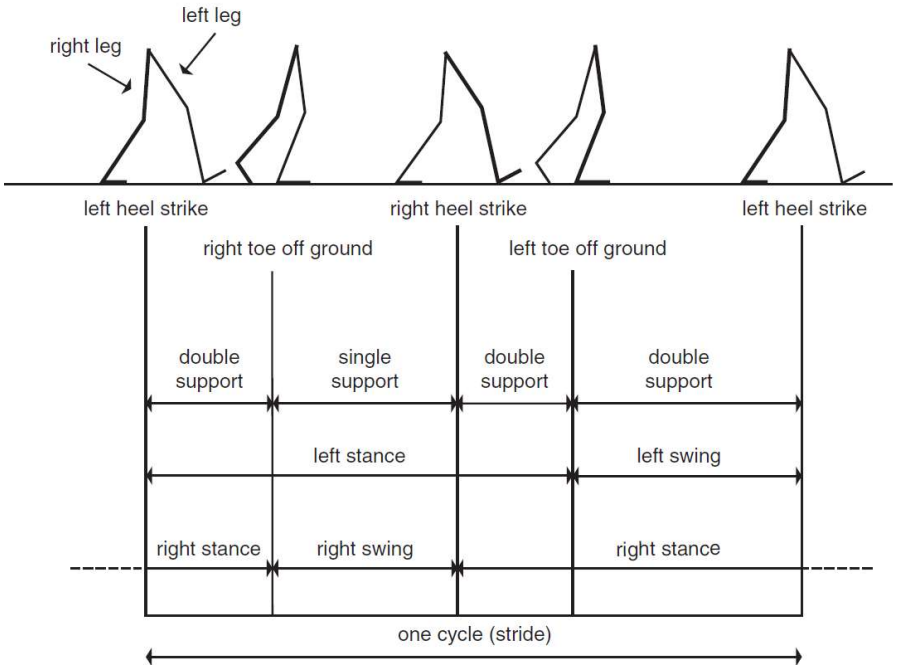
- Reaching and Grasping
  - Coordinated motion
    - More Dofs involved, more difficult
  - Reaching around obstacles
    - Potential field
    - Global path planning (Probabilistic roadmaps, PRMs, Rapidly-exploring random trees, RRTs)
  - Strength
    - Once reached, need to be able generate enough force for manipulation
    - A good criterion for motion naturalness
    - Given a posture, needs to be able to evaluate the maximal torques/forces output

Modeling and Animating Human Figures

- Walking
  - Complex, difficult to model, extensive trial-and-error
  - Cyclic/acyclic motions, multiple purposes (e.g. transport figure and keep balance)
  - Dynamically stable but not statically stable
  - Style variations

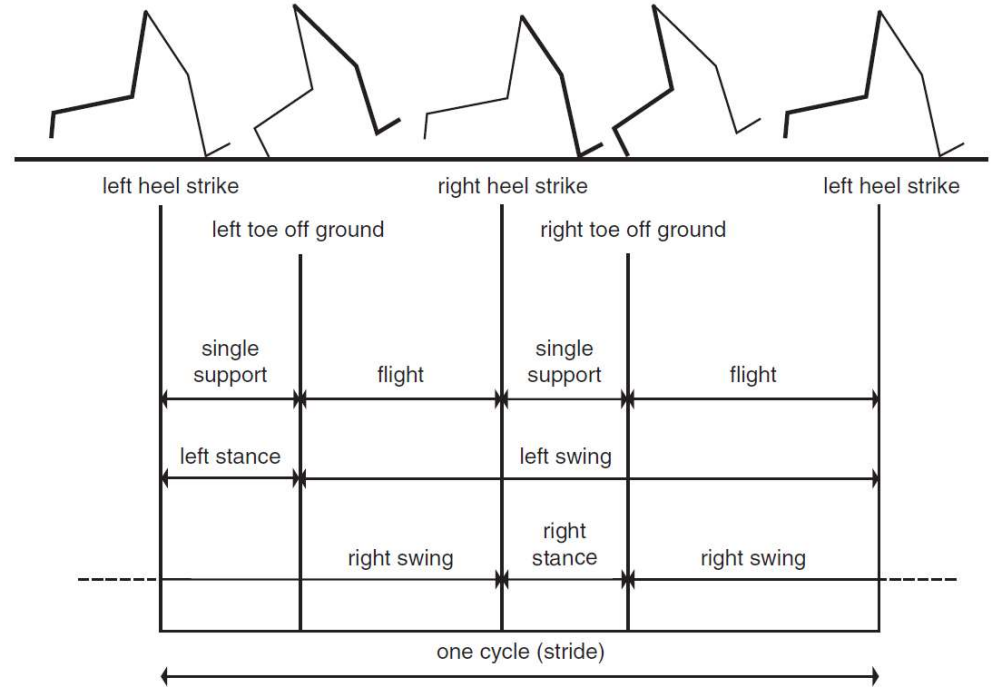
Modeling and Animating Human Figures

- Walking
  - The mechanics
    - Walk cycle



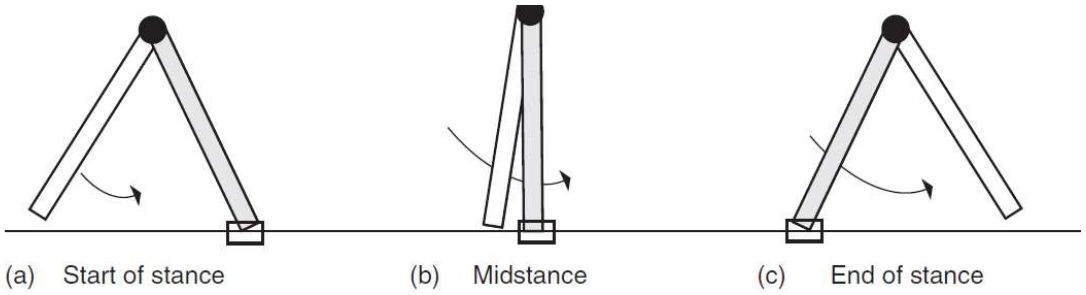
Modeling and Animating Human Figures

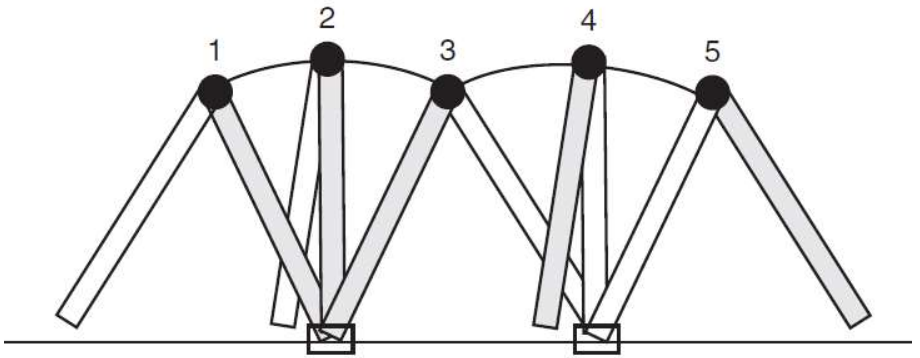
- Walking
  - The mechanics
    - Run cycle



Modeling and Animating Human Figures

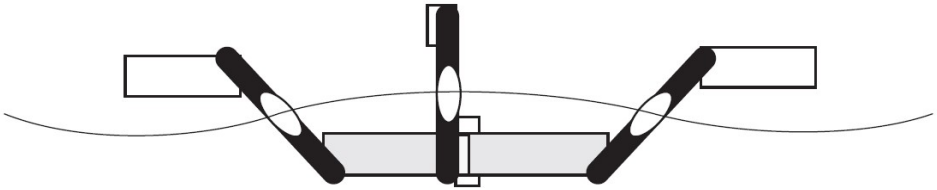
- Walking
  - The mechanics
    - Pelvic Transport





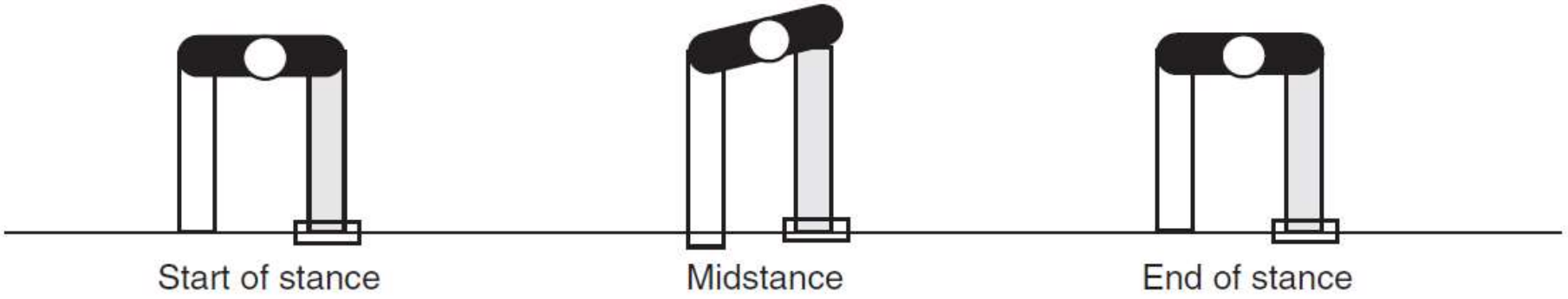
Modeling and Animating Human Figures

- Walking
  - The mechanics
    - Pelvic Rotation



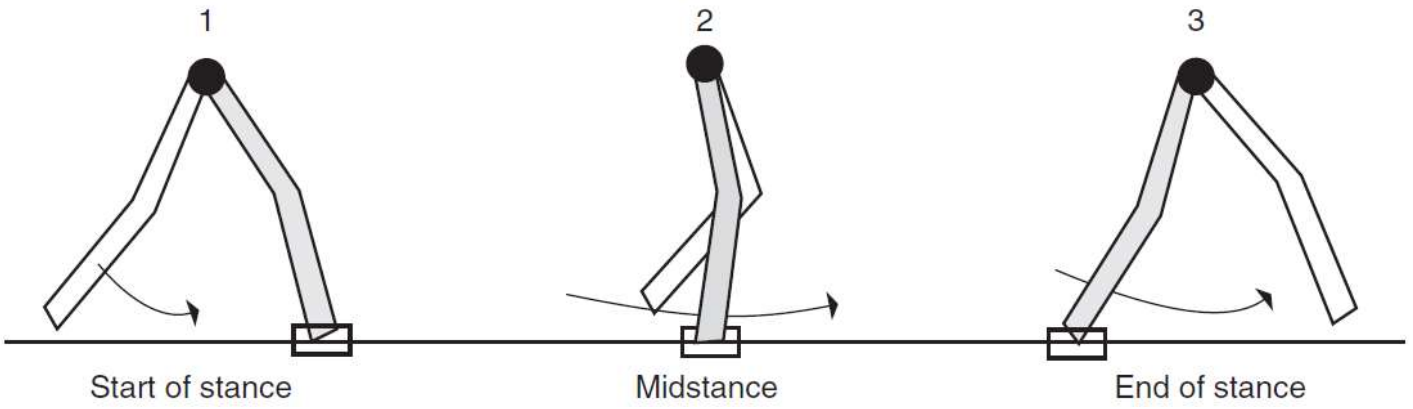
Modeling and Animating Human Figures

- Walking
  - The mechanics
    - Pelvic list to reduce lift



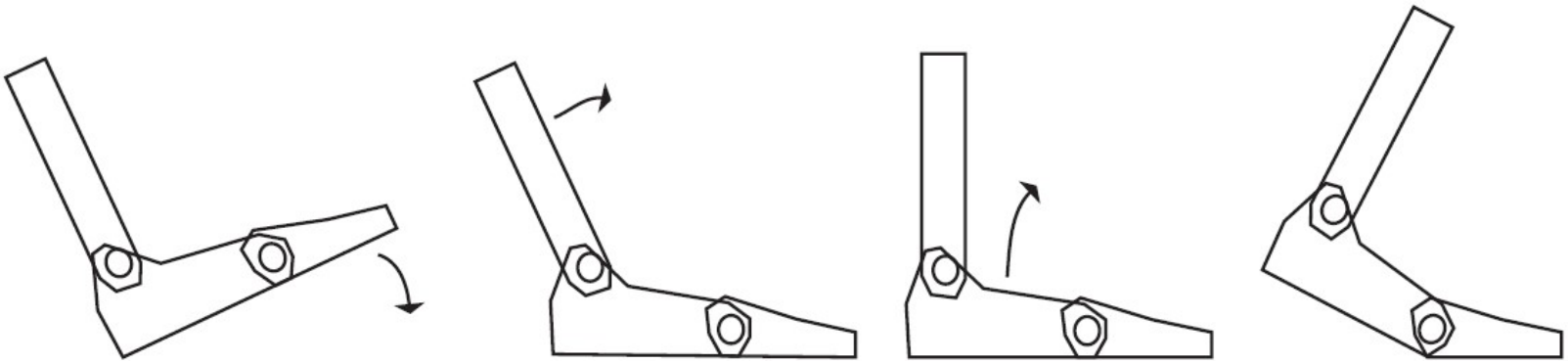
Modeling and Animating Human Figures

- Walking
  - The mechanics
    - Knee flexion



Modeling and Animating Human Figures

- Walking
  - The mechanics
    - Ankle and Toe joints

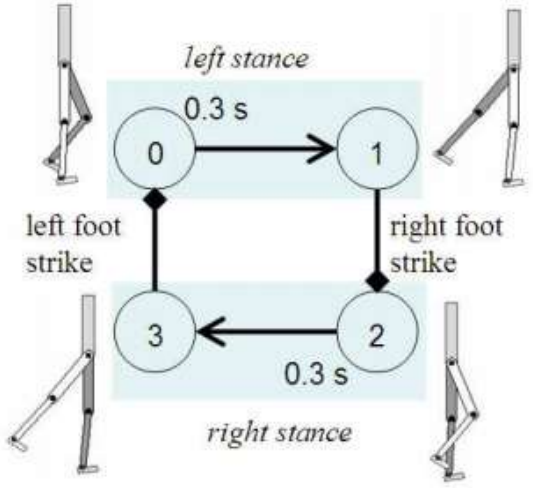


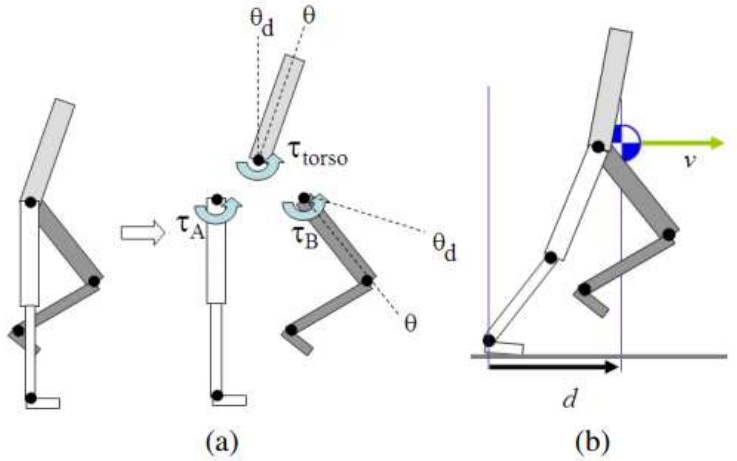
Modeling and Animating Human Figures

- Walking
  - The kinematics of the walk
    - Key-frame joint angles (foot sliding)
    - Inverse Kinematics (unnatural motions)
    - Take a lot of effort
    - Try it in Maya

Modeling and Animating Human Figures

- Walking
  - The dynamics of the walk (Yin et al. Siggraph 2007)





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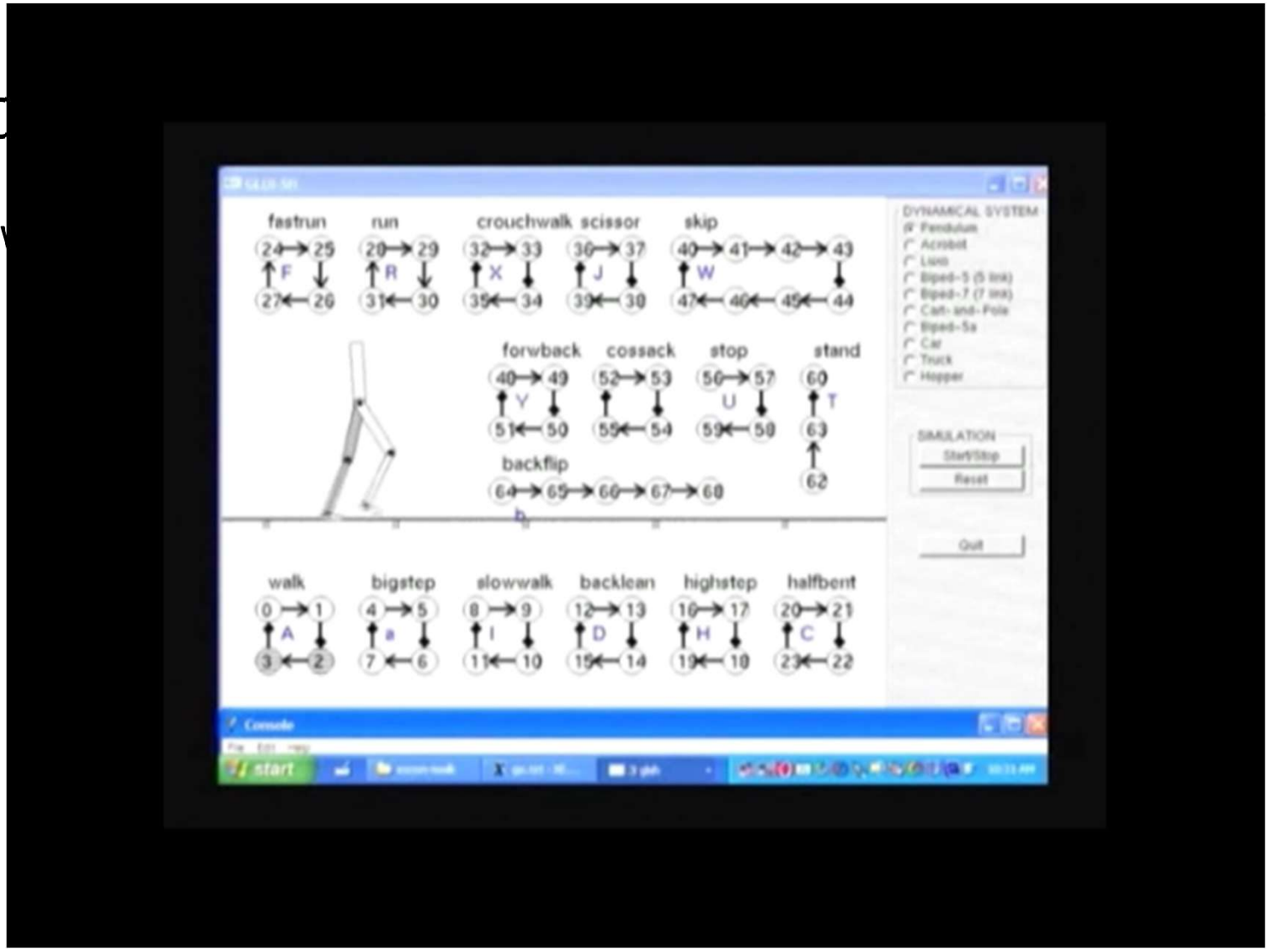
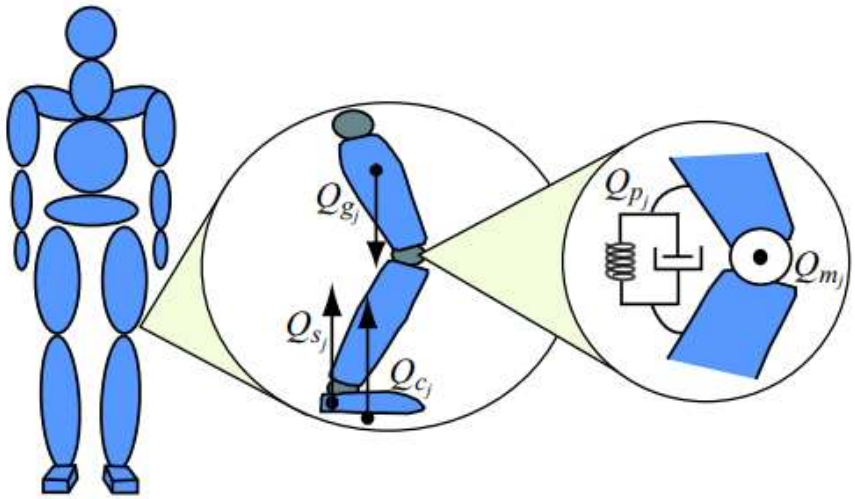
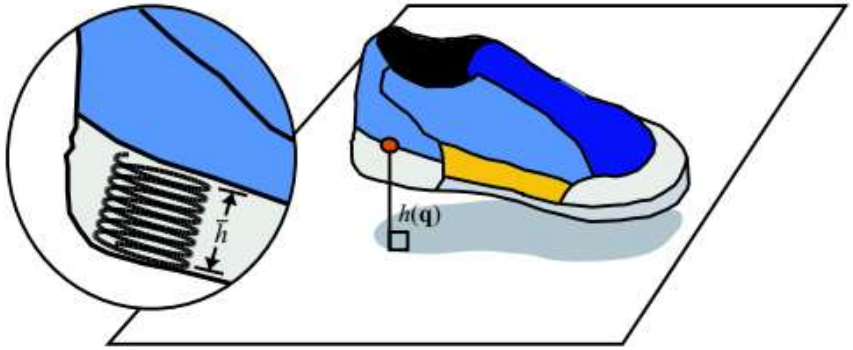

festrun
run
crouchwalk
scissor
skip
forwback
cossack
stop
stand
backflip
walk
bigstep
slowwalk
backlean
highstep
halfbent
DYNAMICAL SYSTEM
Pendulum
Acrobot
Lam
Biped-5 (5 link)
Biped-7 (7 link)
Cart- and- Pole
Biped-5a
Car
Truck
Hopper
SIMULATION
Start/Stop
Reset
Quit
Console
start

Modeling and Animating Human Figures

- Walking
  - The dynamics of the walk (Liu et al. Siggraph 2005)





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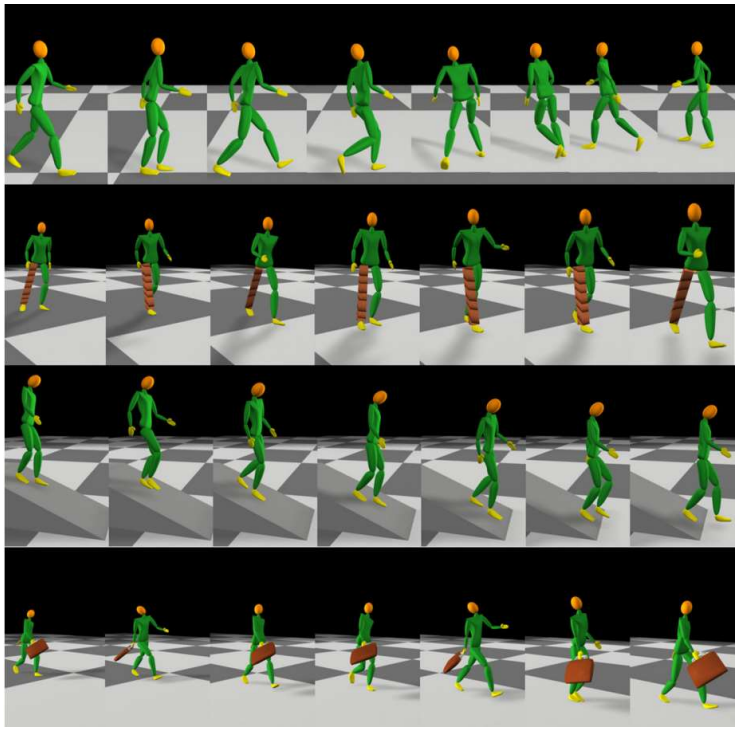
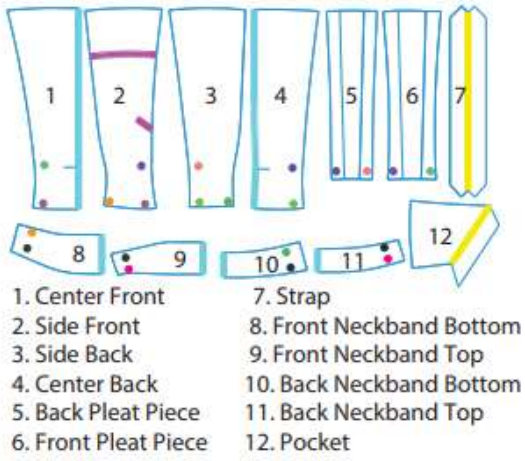
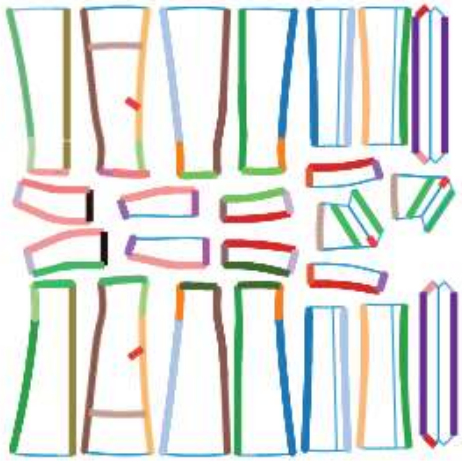
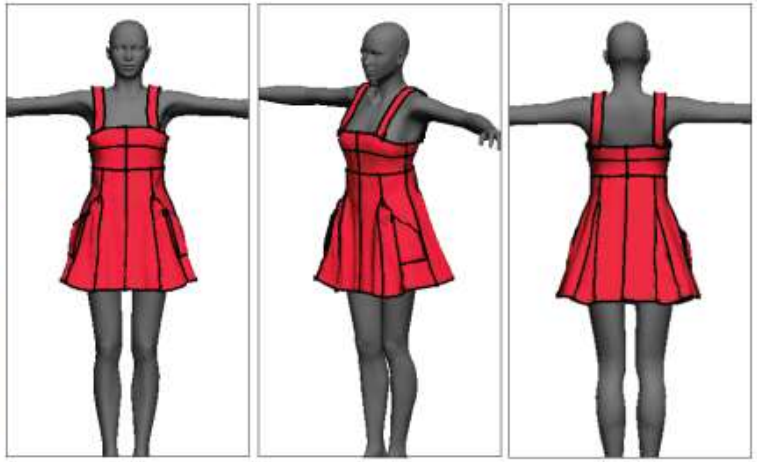


Modeling and Animating Human Figures

- Clothing (Berthouzoz et al. Siggraph 2013)







Modeling and Animating Human Figures

- Clothing (Pons-Moll et al. Siggraph 2017)

Modeling and Animating Human Figures

- Hair
  - Beam and simulation

Data-driven (Chai et al. Siggraph 2017)