Introduction

- Natural looking motion is one of the major goals in the (Human-) Character Animation

- Possibilities:
  - Motion Capturing (mostly used in the industry)
  - Fixed Positions per Frame (e.g. Pose to Pose, Path Animation)
  - Physics
The Approach

- **Parametrizable Motions** (easy to produce similar but different Motions (e.g. for realistically looking Group Behaviour))
- **Dynamic Simulation with Control Algorithms**
- **Reacts on unpredictable runtime events** (UserEvents)
- **Multiple Levels of Animation**
  - Secondary Motion (Clothes, Hair)
  - Group Animation (Obstacle Avoidance, Group Behaviours)
Background

- **Animating Human Motion**
  - Robotics
    - Control Algorithms a partly based on Robot Equations
  - Biomechanics
    - provides MoCap data, forceplate data, muscle activation records
    - Energy curves for walking and running
    - Energy Usage during Locomotion
    - Stance-, Flight-Duration, Step Length as a speed function ...

- **Computer Graphics**
  - provides IK
  - Graphics

*Motivation: Endorphin Engine Video*
The Models

- Constructed from rigid links connected by rotary joints
- Basic Calculation: Moment of Inertia for each body part (density data measured from cadavers)

<table>
<thead>
<tr>
<th>Model</th>
<th>Body Parts</th>
<th>Degrees OF</th>
</tr>
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<tbody>
<tr>
<td>Gymnast</td>
<td>15</td>
<td>30</td>
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<tr>
<td>Runner</td>
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<tr>
<td>Bicyclist</td>
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</tbody>
</table>
The Animated Motions in this Approach

- Running
- Bicycling
- Handspring Vault
Running

- Cyclic movement
- Legs swing fore and aft, provide support for body in alternation
- Muscles have different control in different times of the cycle
  - Stance Phase: support and balance
  - Flight Phase: move the leg forward in preparation for next touchdown (active leg)

Use a State Machine for the Movement
State Machine and transition Events

- Idle leg
  - Ball of foot leaves Ground
  - Knee extended
  - Toe contact
  - Percentage of stance phase complete

- Unloading

- Flight

- Loading
  - Heel touches Ground
  - Knee bends

- Heel contact
  - Ball of foot touches Ground

- Active leg
Controlled Movement

• Active Leg swings forward in preparation for touchdown
• Speed Control
  • Place average Point of Support under hip
  • Notice the change in contact point from heel to metatarsus
Controlled Movement

Touchdown

- At touchdown, the desired distance from hip to heel projected onto the ground plane is

\[ x_{hh} = \frac{1}{2}(t_s \dot{x} - \cos(\theta)l_f) + k(\dot{x} - \dot{x}_d) \]

\[ y_{hh} = \frac{1}{2}(t_s \dot{y} - \sin(\theta)l_f) + k(\dot{y} - \dot{y}_d) \]

- \( t_s \): estimated time where foot on the ground
- \( x, y \): Velocities of the Runner on the Plane
- \( x_d, y_d \): the desired velocities
- \( \Theta \): Facing Direction of Runner
- \( l_f \): Distance from the heel to the ball of the foot
- \( k \): Gain for correction of errors in speed

\( z_{hh} \) is computed by the fixed length of the leg.

With \( x_{hh}, y_{hh}, z_{hh} \), the IK for the leg provides knee and hip angles.
Controlled Movement
Stance Phase

- Knee acts as passive spring to store kinetic energy (taken from touchdown phase)
- Phases of Stance:
  - heel contact
  - toe moves toward ground
  - Ball of foot contact triggers the transition from „heel contact“ to „heel and toe contact“ (State Machine)
  - „heel to toe contact“ happens after 30-50% of stance duration (depending on the speed)
  - Proportional derivate servos compute torques for hip joint of the stance leg -> The body’s Roll, Pitch and Yaw move toward desired values
  - Ankle joint extends, causing heel to lift

Adding energy for the next : Flight Phase
Controlled Movement

Flight Phase

- Idle leg reduces disturbances to the body attitude caused by the swinging active leg
- Hip angles mirror the motion of active leg to reduce net torque on the body
- Control laws compute desired Values for each joint, and PD Servos control the positions.

For each Joint, the desired torque is

\[ \tau = k_s (\theta_d - \theta) + k_d \dot{\theta} \]

- \( k_s \) is the spring gain
- \( k_d \) is the damper gain
- \( \theta \) is the current and desired angle of DOF
- \( \dot{\theta} \) is the velocity of joint

Resulting torque

Velocity of joint
Controlled Movement^5
Upper Body

- Shoulder joint swings arm for and aft, synchronized with the legs motion

- Motion of upper Body is important:
  Counter oscillating Arms reduce yaw oscillation

- Control law compute values for each joint

- PD Servos control the joint‘s positions
Bicycling

- Bicycler controls speed and direction by applying forces to handlebars and pedals
- Rider is attached to the bike by a pivot joint between the seat and the pelvis
Bicycling

- Adjusting the velocity of the bicycle by the torque at the crank

\[ T_{\text{crank}} = k(v - v_d) \]

- We assume that the legs are most effective at pushing downwards. So here is a weighting function

\[ W = \frac{\sin(\theta_{\text{crank}}) + 1}{2} \]

\( \theta_{\text{crank}} \) is zero when crank is vertical, and right foot above left.
Bicycling

- Overall, the force on the pedal, that the leg produce:

\[ f_l = \frac{W \ T_{\text{crank}}}{L} \]

\[ f_r = \frac{(1-w) \ T_{\text{crank}}}{L} \]

fl, fr: desired forces from left and right leg

l: Length of the crank arm
Bicycling

- **Steering:**
  - Control Algorithm computes desired Angle for the Fork based on the errors in roll and yaw
  - Yaw Angle is set by the user of high-level control algorithms
  - IK is used to compute shoulder and elbow angles, that position the hands on the handlebars for the computed fork angle $\theta_{fork}$
  - Proportional-derivative servos move shoulder and elbow joints toward the angles.
Bicycling

- Waist and Wrists are held at a nearly constant angle with PD servos
- Ankle joints are controlled to match data, originally recorded from human subjects (Studies of Pedaling Mechanics in Biomechanics)
- Positional Constraints are used to “glue” the feet to the pedals
Vaulting Horse and Balancing

- Springboard, to jump toward the vaulting horse
- Push off the horse with hands
- Land on the feet on the other side of the horse

„Hansspring Vault“ with full somersault
Vaulting Horse and Balancing

6 Steps:
- Hurdle step
- Board contact
- First flight
- Horse contact
- Second flight
- Landing

Animation begins during the flight phase preceding touchdown on the springboard
Vaulting Horse and Balancing
Jump off and first Flight phase

- Springboard force is calculated based on a linear Spring/Damper model
- Springboard deflects Max: Knee extends, pushing on spring board, adding energy to the system
- Rebounding Springboard launches gymnast to air, first flight phase begins
Vaulting and Balancing
Reaching the vault

- Control System prepare Gymn.‘s hands on the horse by positioning the shoulder on the line between the shoulder and the desired hand position on the vault

\[ \gamma_{yd} = \lambda_y - \Phi \]

\( \gamma_{yd} \): desired Shoulder Angle relative to the body
\( \Phi \): Pitch Angle of the body
\( \lambda_y \): Angle between vertical and a vector form shoulder to desired hand position
Vaulting and Balancing
Jumping over the Vault

- Gymnasts hands contact the vault
- Arms are held straight
- No torque is applied at shoulder or wrist
- Forward velocity carries Gymn. over Horse
- When the Hands leave the vault, the second flight phase begins
Vaulting and Balancing
2nd Flight Phase

- Feet spread slightly to give larger area of support at touchdown
- While landing on the ground, the system must remove the horizontal and rotational energy from somersault and establish an upright, balanced position
- Knees and waist are bent to absorb energy
- If the center of mass passes over the polygon formed by feet, a balance controller* is activated.

*Video: Dojo Fight
Group Behaviours

- Calculating desired Position for each Individual

- Averaging location and velocity of Neighbours used to calculate the Group Velocity

- Respecting Obstacles
Secondary Motion

- Passive System
- Enhance the Scene’s Realism
- Possible to drive by rigid body motion (Sweatpants, Hair)
- Often very complex internal Physics (Splashing Water)
Discussion

- Limited Number of Behaviors (Library)
- How can additional control algorithms be easier generated? (Toolbox)
- Still time consuming to develop Behaviors step-by-step
- Simplify the Behavior System by automatic Transitions from one Behavior to another
- Add naturalness by limiting the dynamics (constraints)
Discussion


- Are the behaviors robust enough to interact with unpredictable user input?
Conclusion

- Rigid body models can be used to produce natural looking animation
- Expensive computation needed
- Behavior Libraries are hard to design (Very unique Behaviors need special control algorithms)

A hard and stony but worthy path to reach physically realistic human character animations
QUESTIONS ?