Procedural Animation

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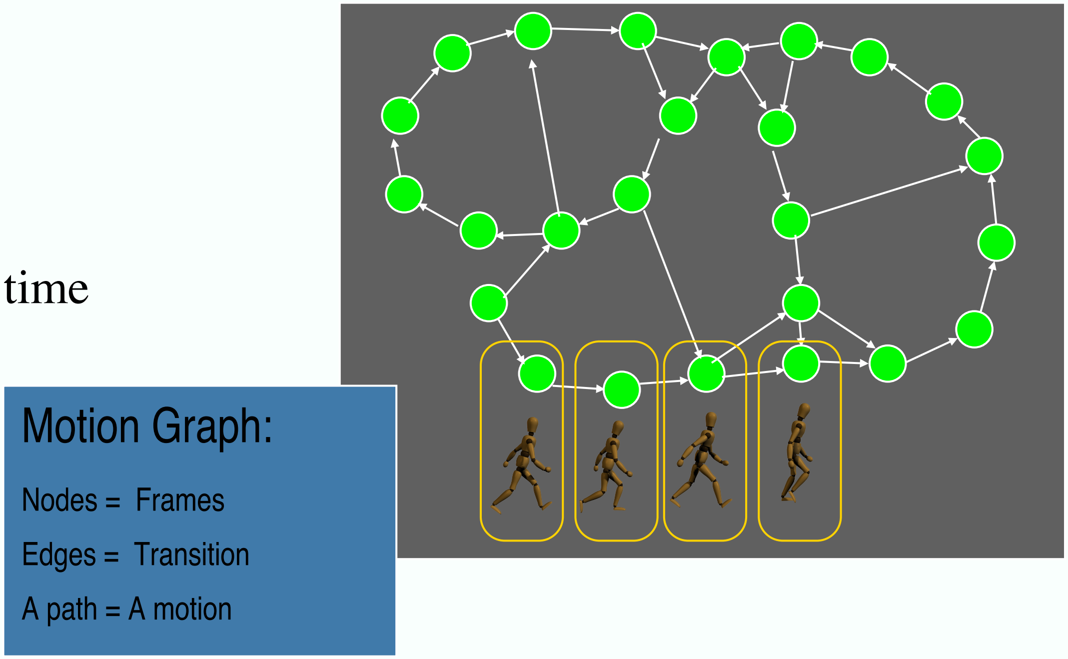
Big points

- Two important types of procedural animation
  - slice and dice data, like texture synthesis
  - build (approximate) physical simulation
- Extremely powerful
  - issues
    - how to slice and dice data well
    - what to simulate

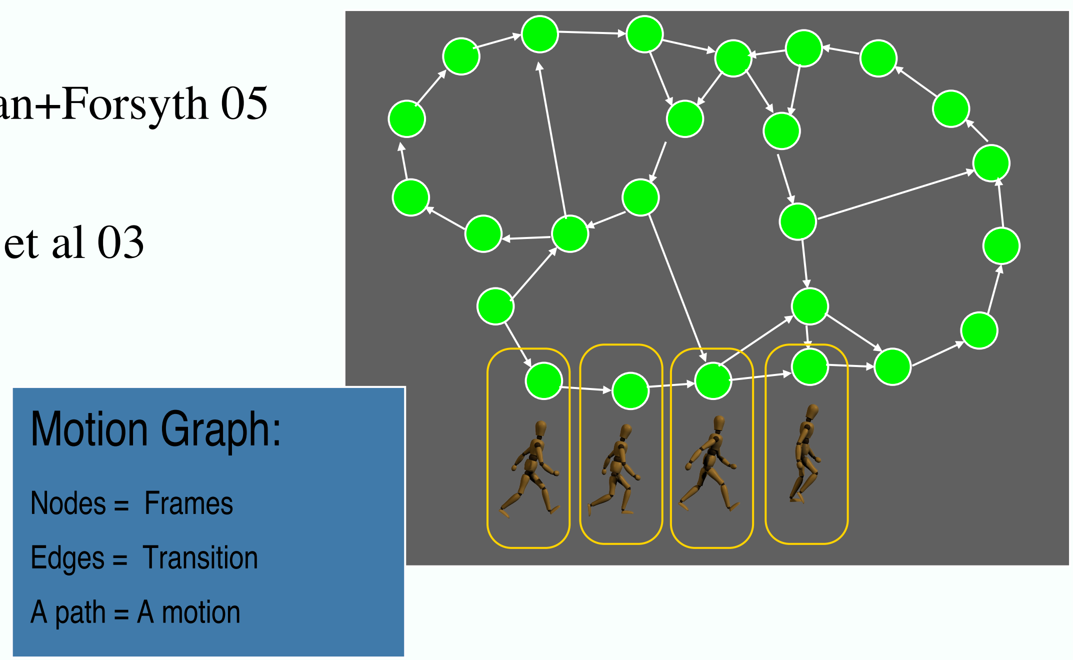
Motion graph

- Take measured frames of motion as nodes
  - from motion capture, given us by our friends
- Directed edge from frame to any that could succeed it
  - decide by dynamical similarity criterion
  - see also (Kovar et al 02; Lee et al 02)
- A path is a motion
- Search with constraints
  - root position+orientation
  - length of motion
  - occupy a frame at specified time
  - limb close to a point



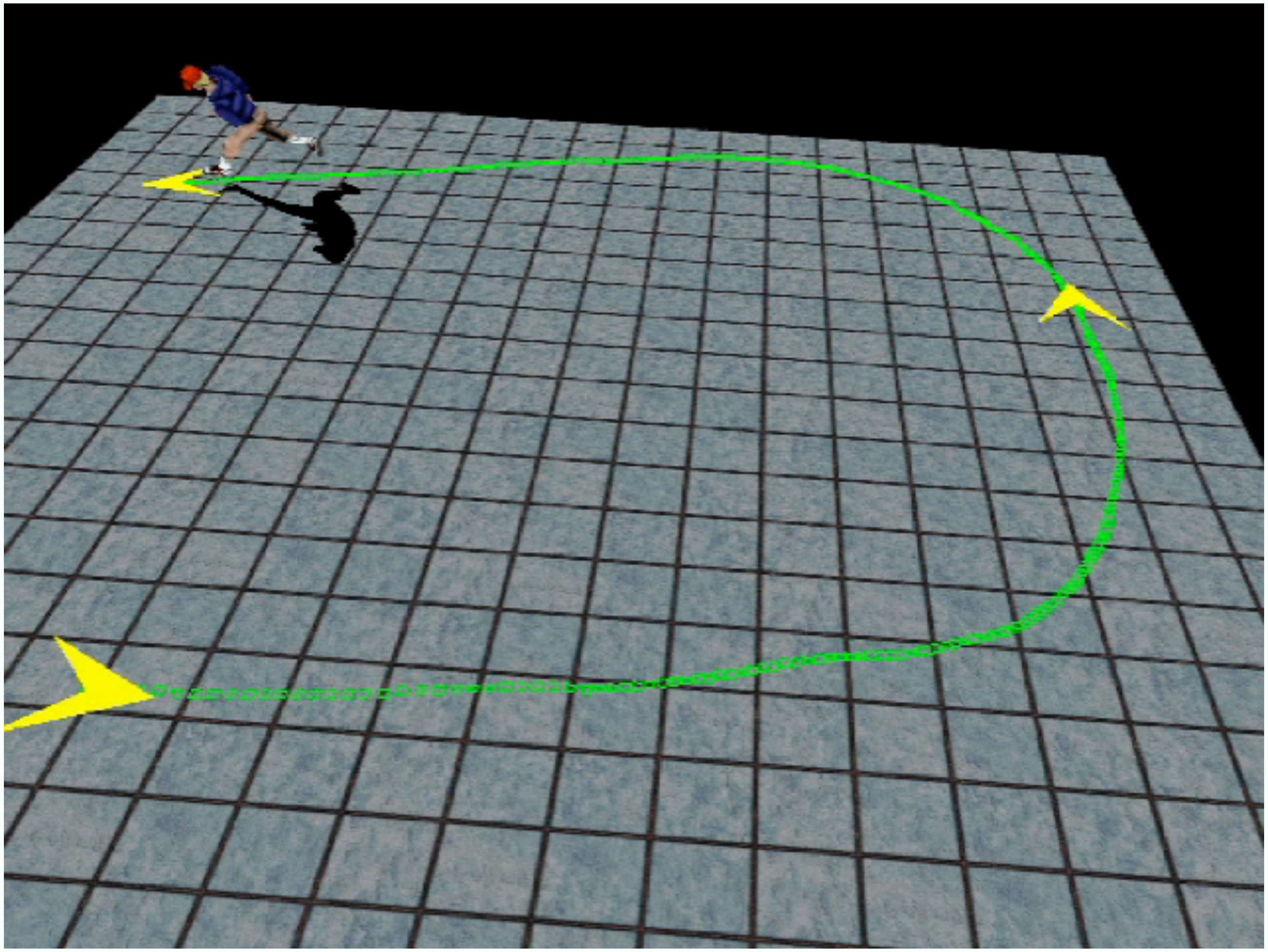
Search in a motion graph

- Local
  - Kovar et al 02
- With some horizon
  - Lee et al 02; Ikemoto, Arikan+Forsyth 05
- Whole path
  - Arikan+Forsyth 02; Arikan et al 03

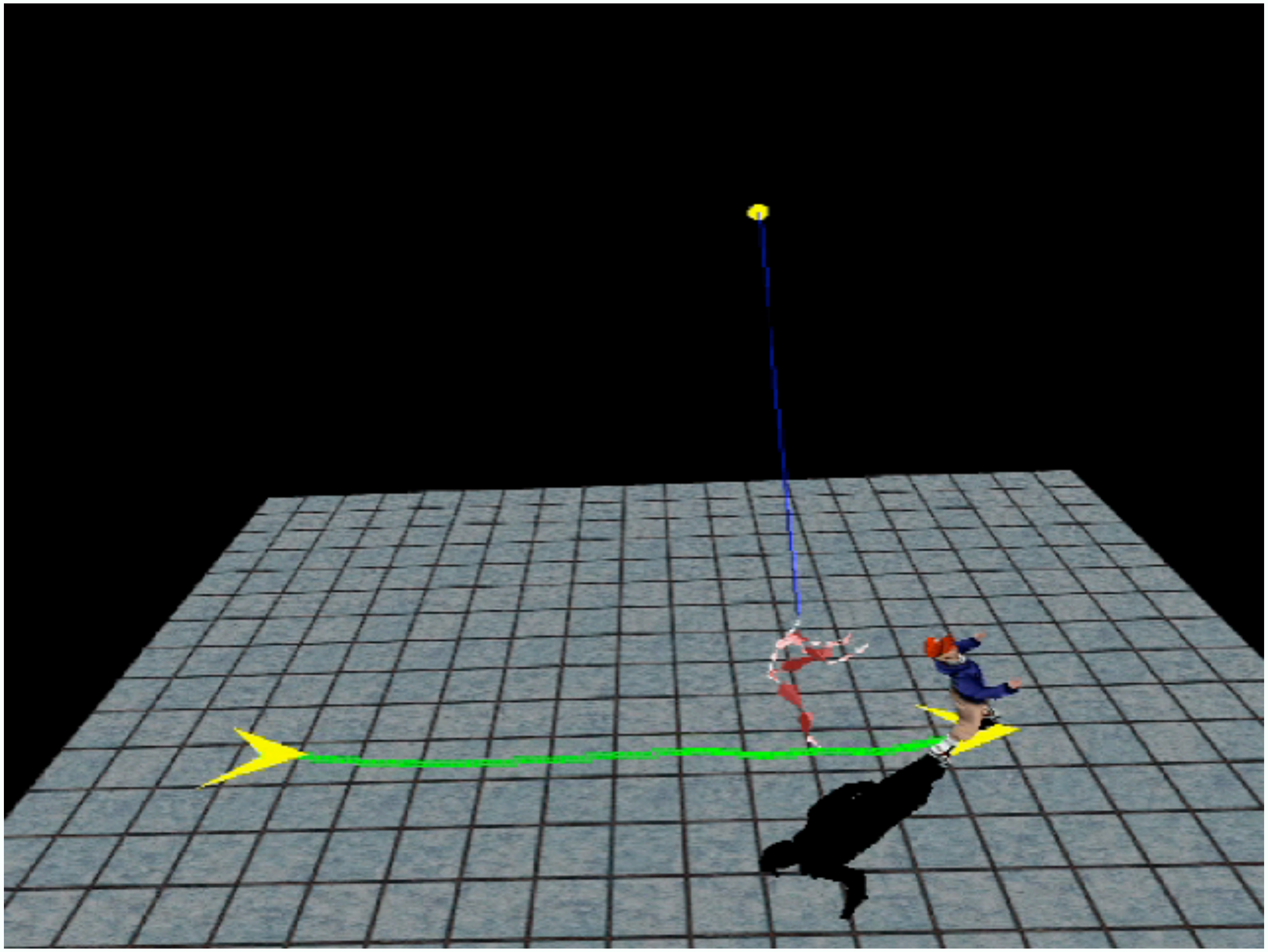


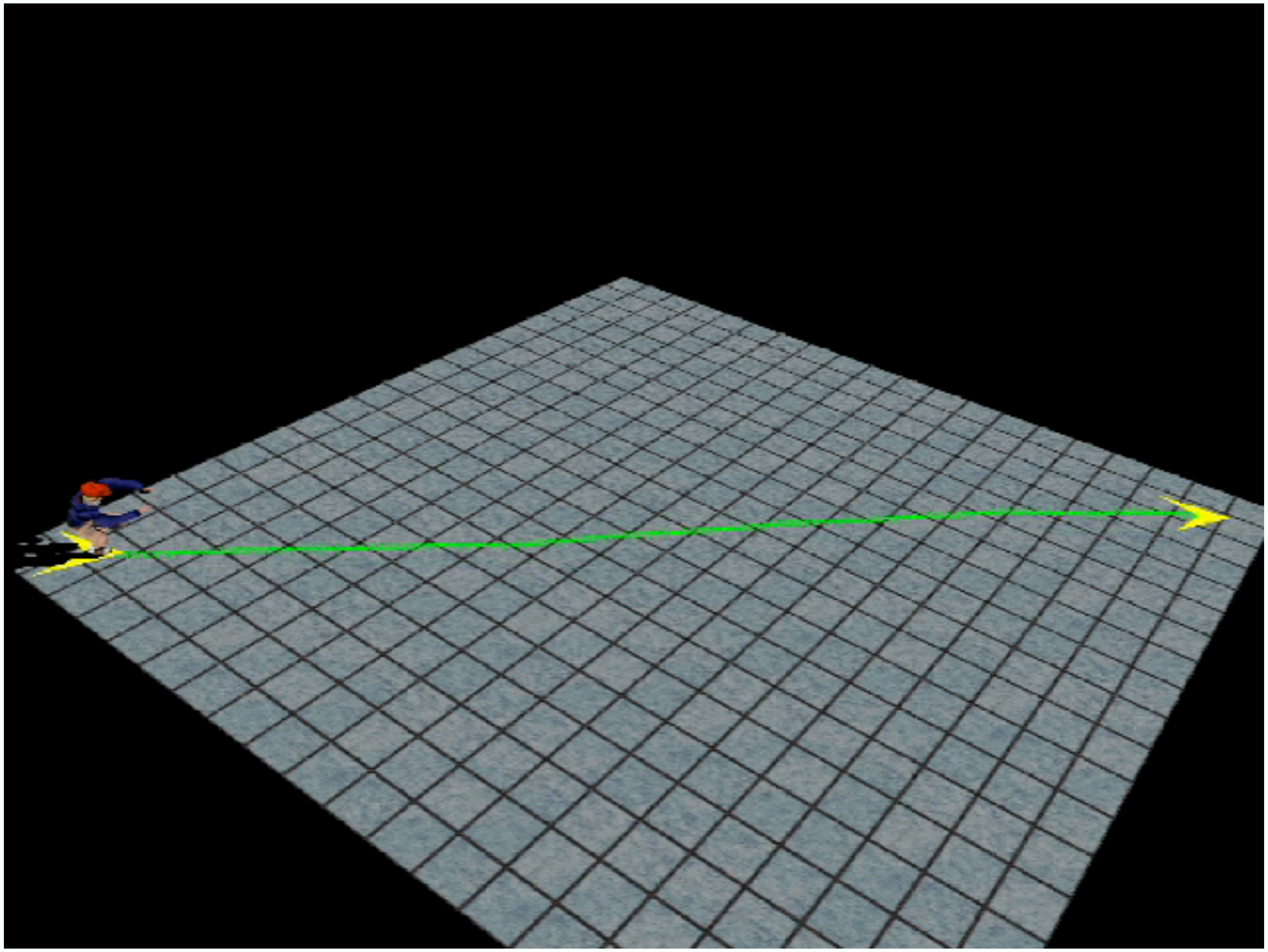
Local Search methods

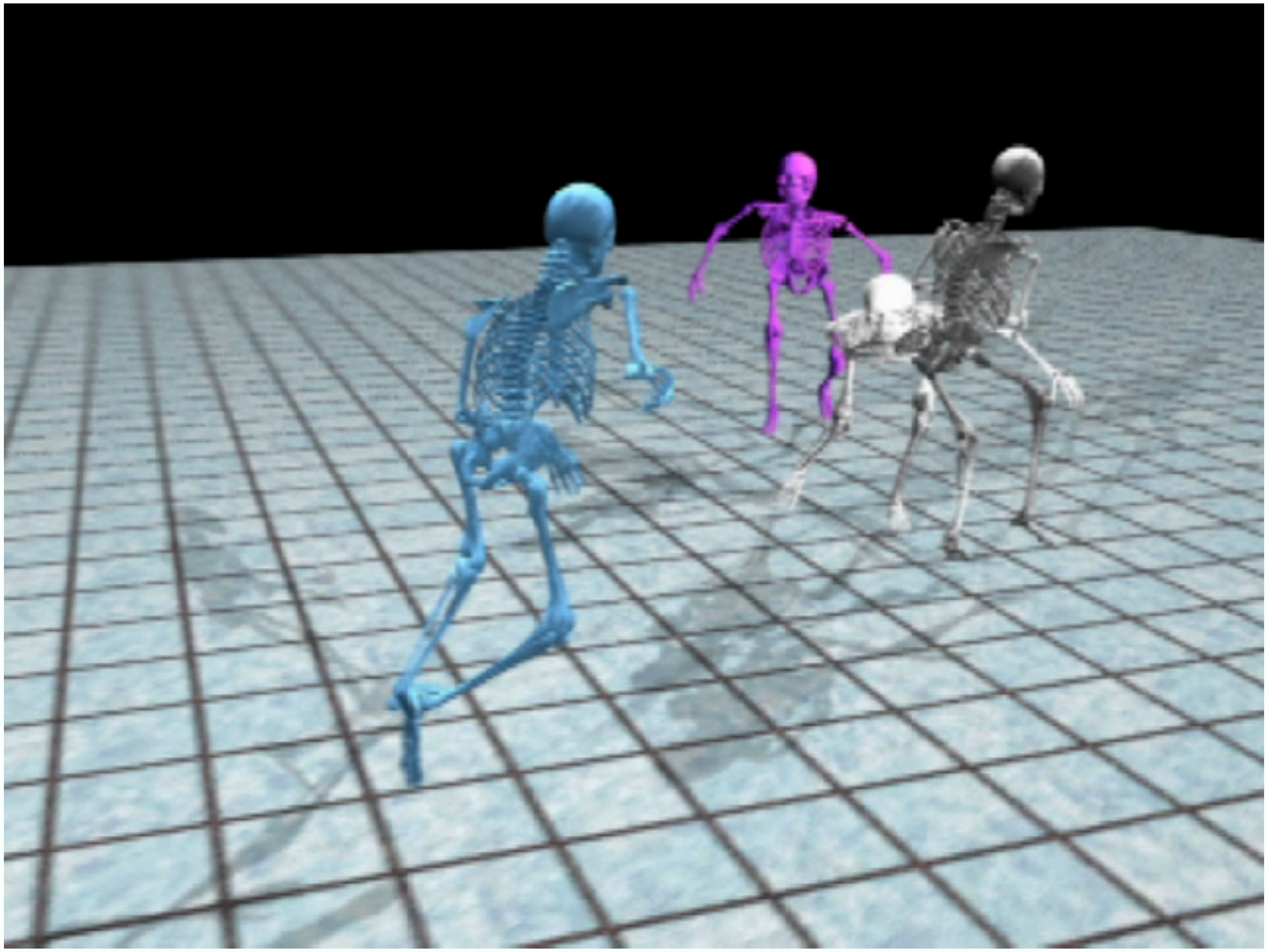
- Choose the next edge (Kovar, Gleicher, Pighin 02)
  - ensure that one can’t get stuck locally
  - but can’t guarantee a goal is available on longer scale



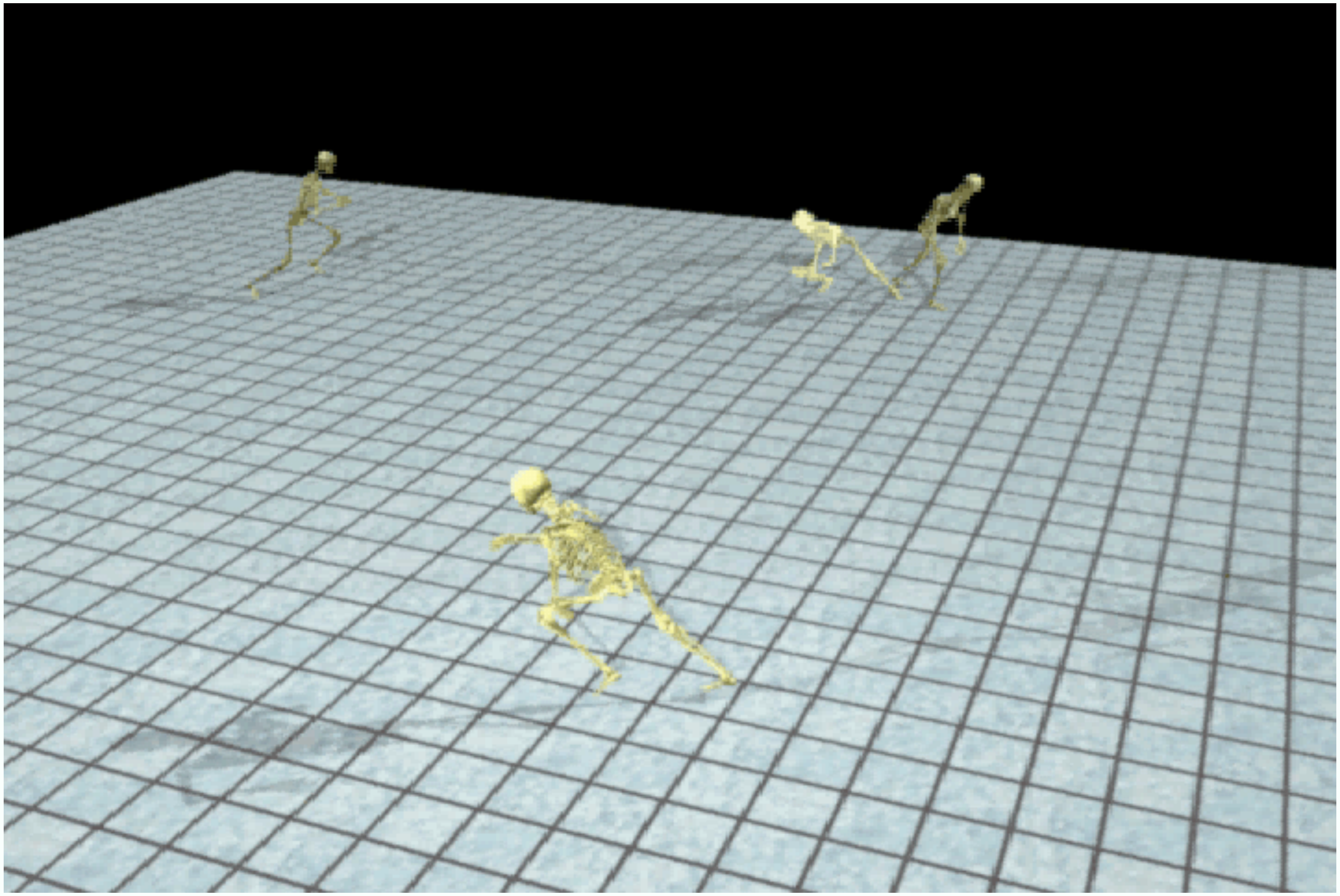
Arikan+Forsyth 02







Arikan+Forsyth 02



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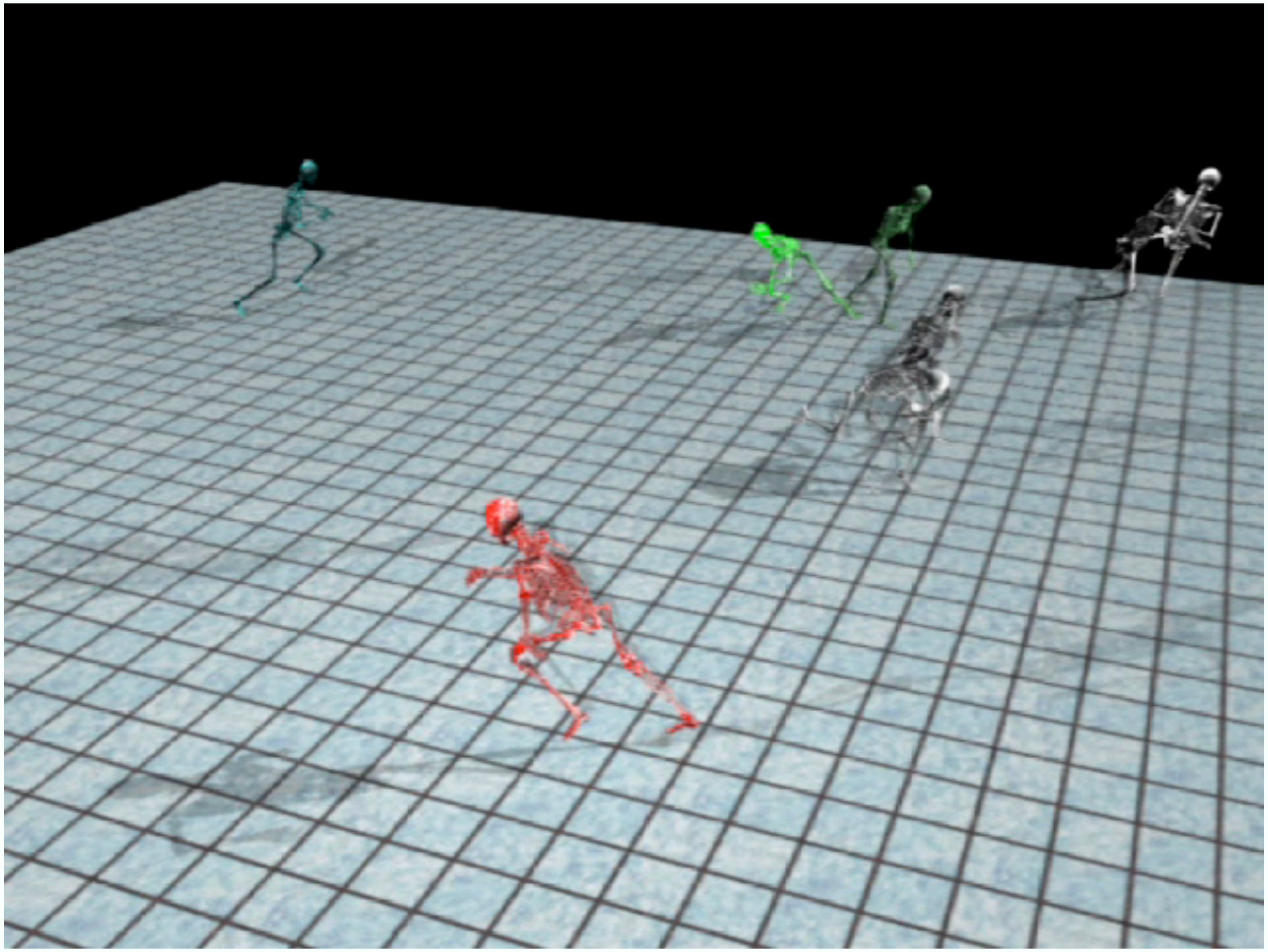
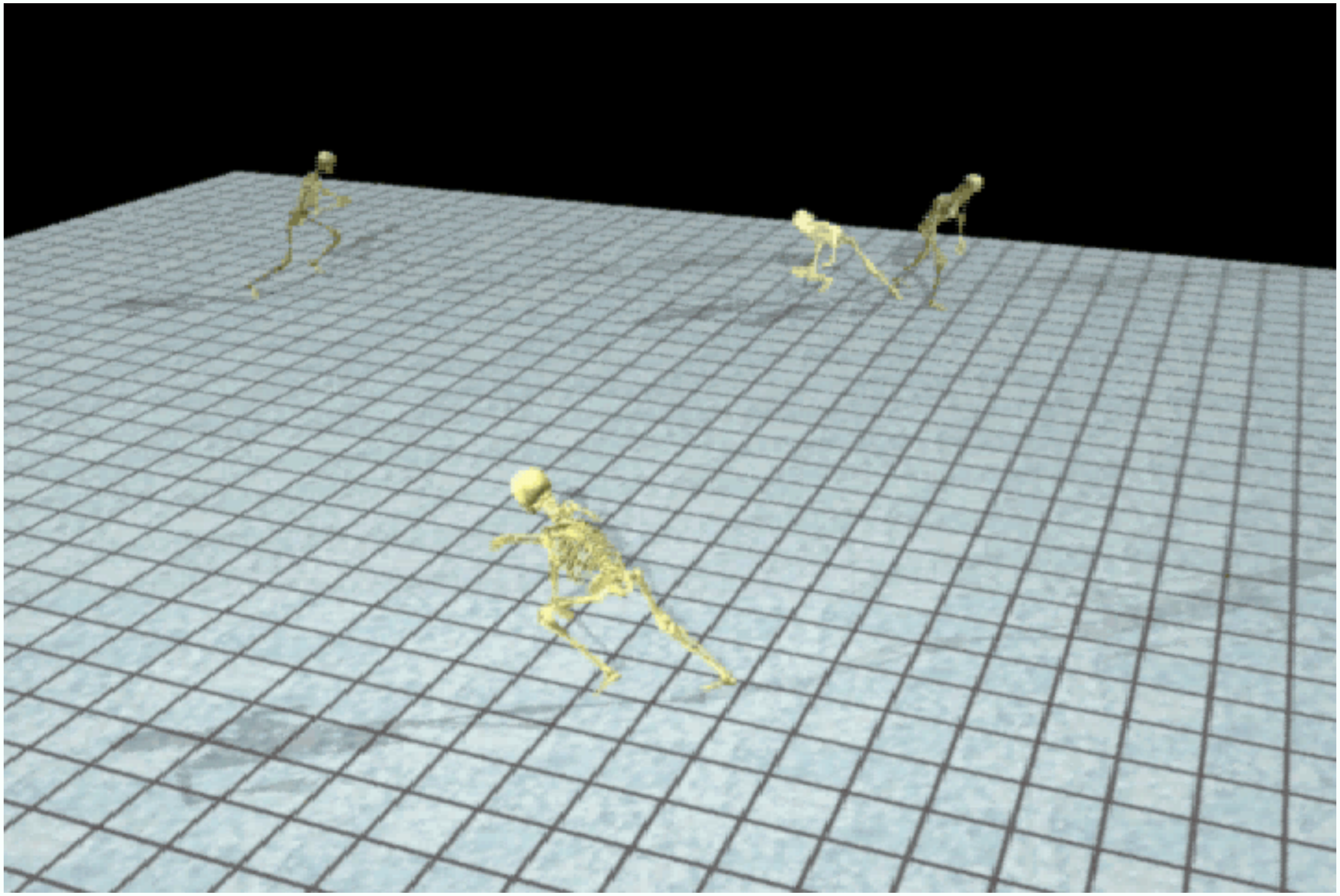


Arikan+Forsyth 02

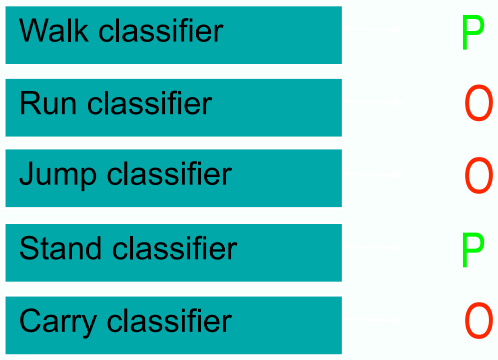


Arikan+Forsyth 02

Annotation - desirable features

- Composability
  - run and wave;
- Comprehensive but not canonical vocabulary
  - because we don't know a canonical vocabulary
- Speed and efficiency
  - because we don't know a canonical vocab.

- Can do this with one classifier per vocabulary item
  - use an SVM applied to joint angles
  - form of on-line learning with human in the loop
  - works startlingly well (in practice 13 bits)

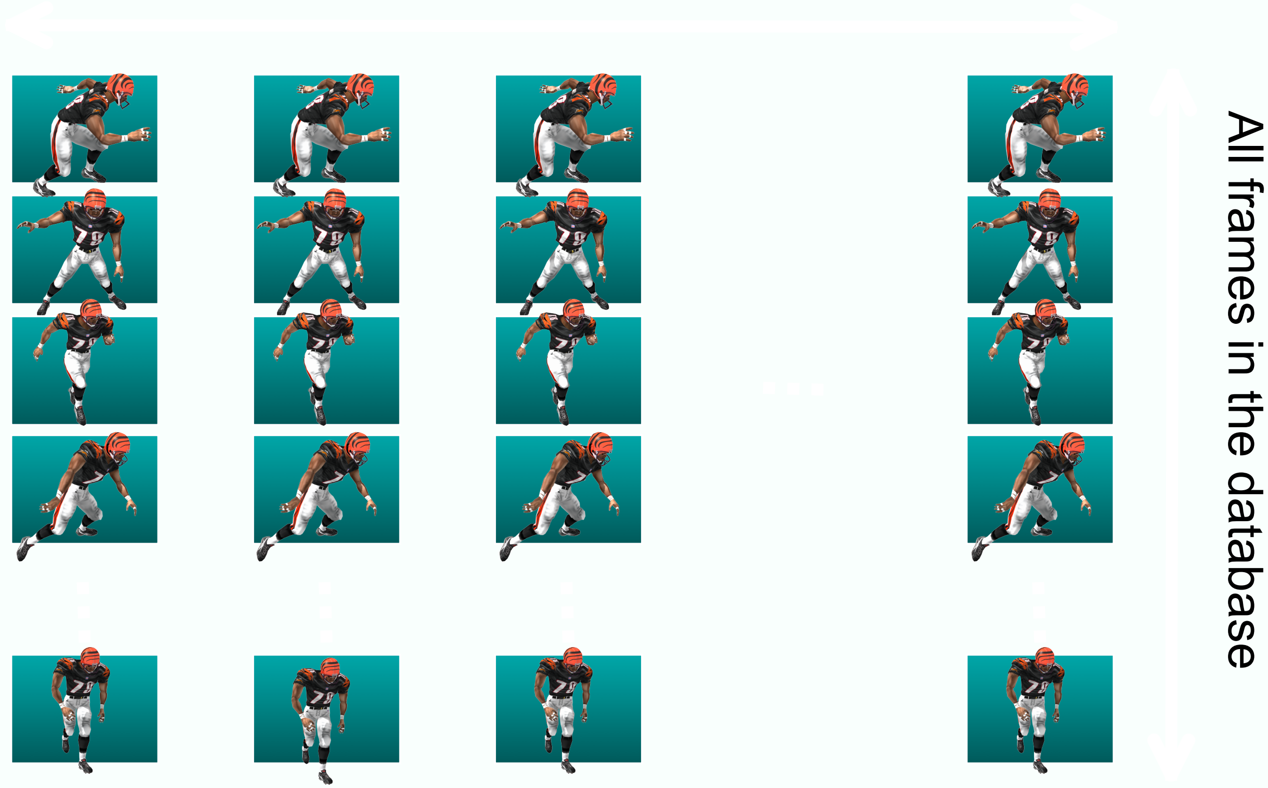


Arikan+Forsyth+O'Brien 03

? ? ? … ? ***n*** - frames

Walk	P	P	P		P
Run	●	●	●		●
Jump	●	●	●	Motion demand	●
Wave	P	P	O		O
Carry	●	●	●		●

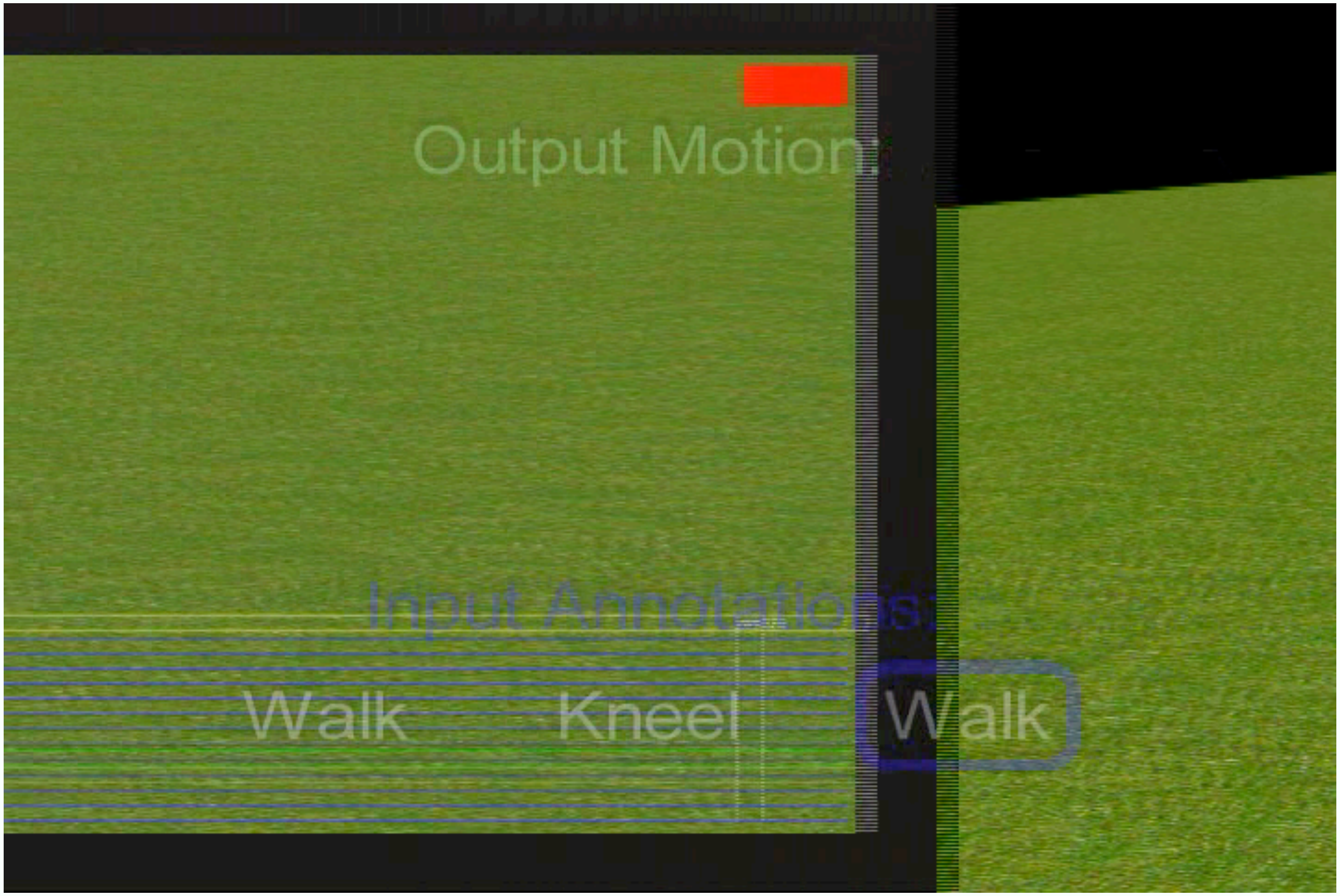
Synthesis by dynamic programming



Arikan+Forsyth+O'Brien 03

Dynamic programming practicalities

- Scale
  - Too many frames to synthesize
  - Too many frames in motion graph
- Obtain good summary path, refine
  - Form long blocks of motion, cluster
  - DP on stratified sample
    - split blocks on "best" path
    - find similar subblocks
      - DP on this lot
        - etc. to 1-frame blocks



Arikan+Forsyth+O'Brien 03

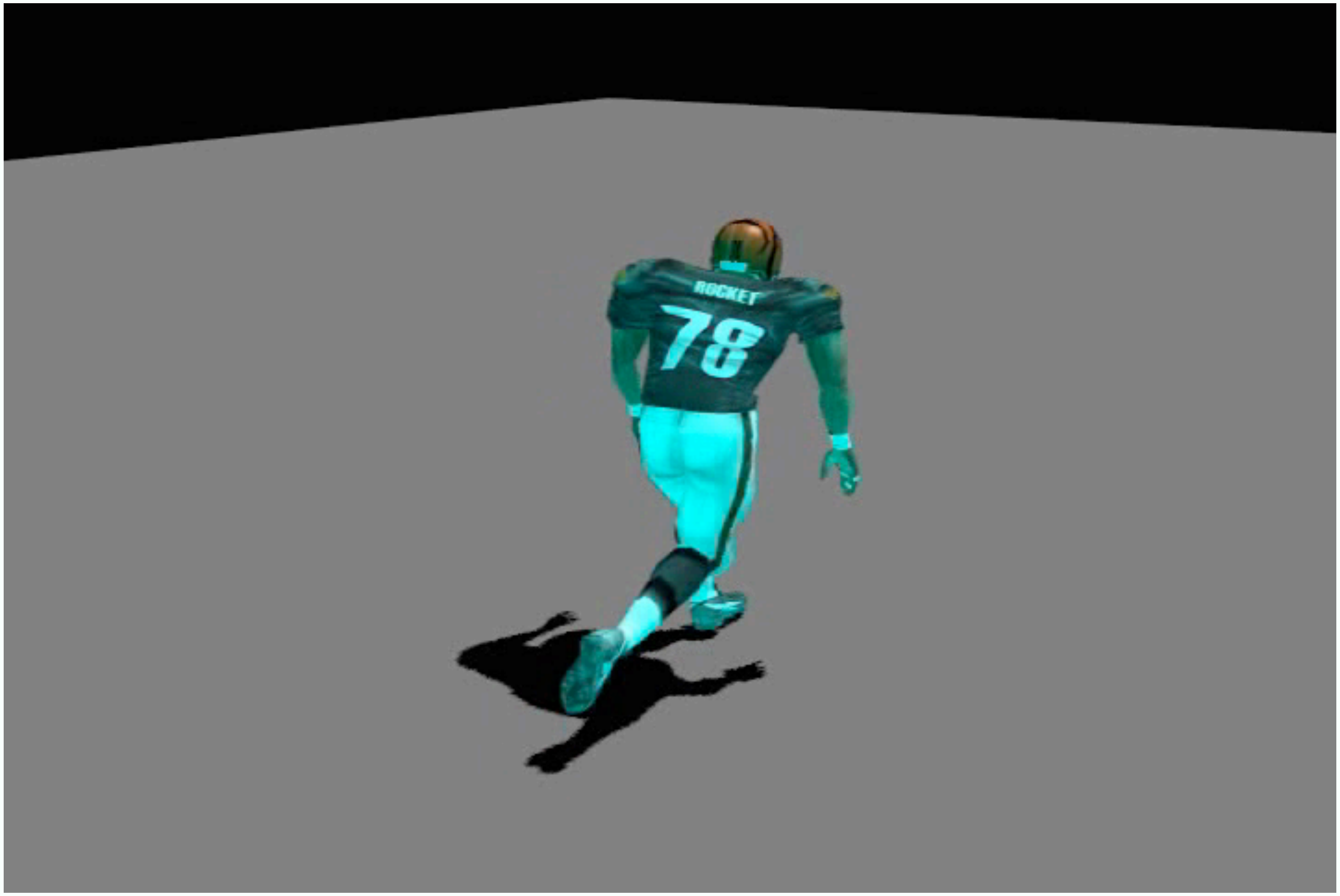
Arikan+Forsyth+O'Brien 03

Transplantation

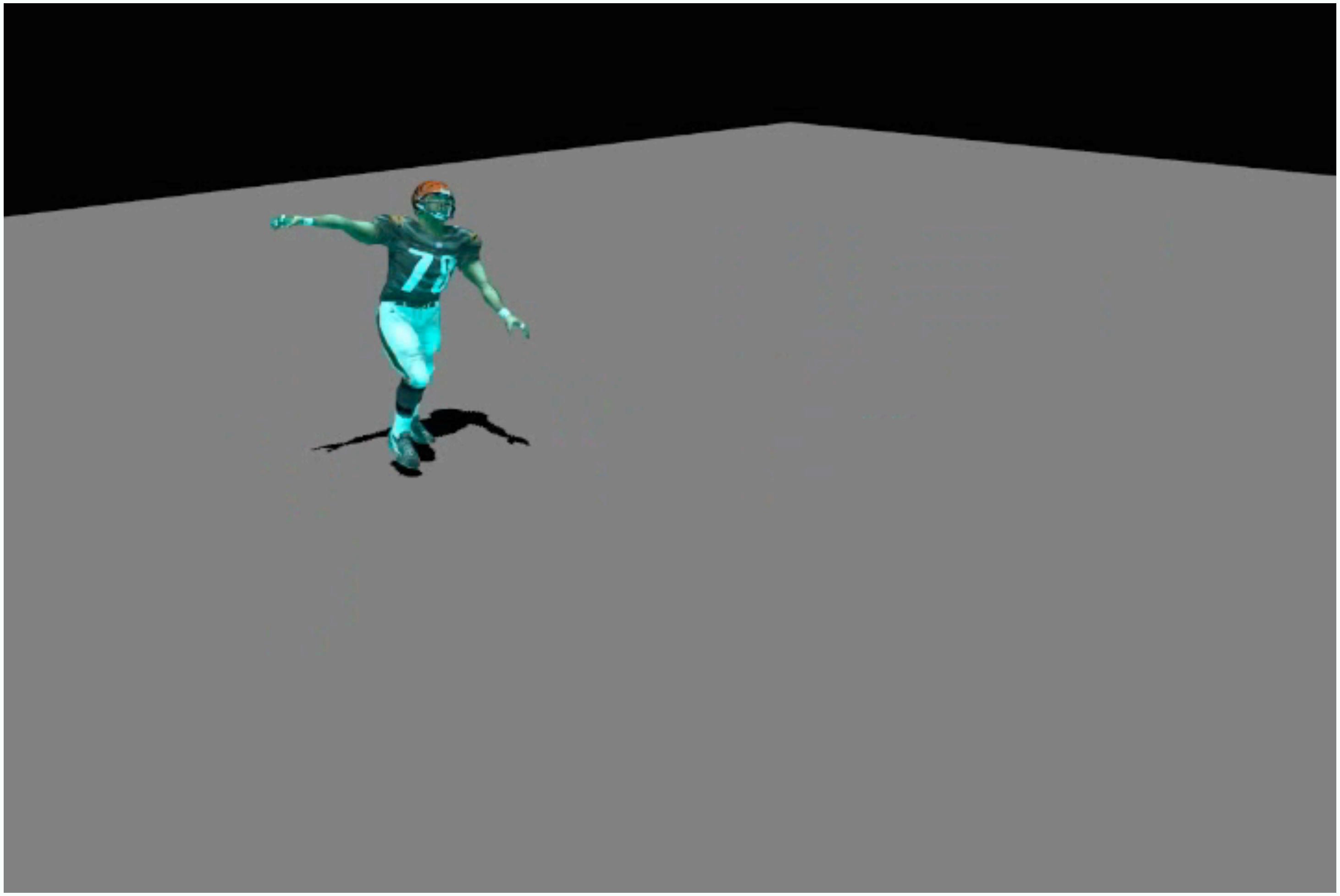
- Motions clearly have a compositional character
  - Why not cut limbs off some motions and attach to others?
    - we get some bad motions
  - build a classifier to tell good from bad
    - avoid foot slide by leaving lower body alone

Ikemoto+Forsyth 04

Ikemoto+Forsyth 04



Ikemoto+Forsyth 04



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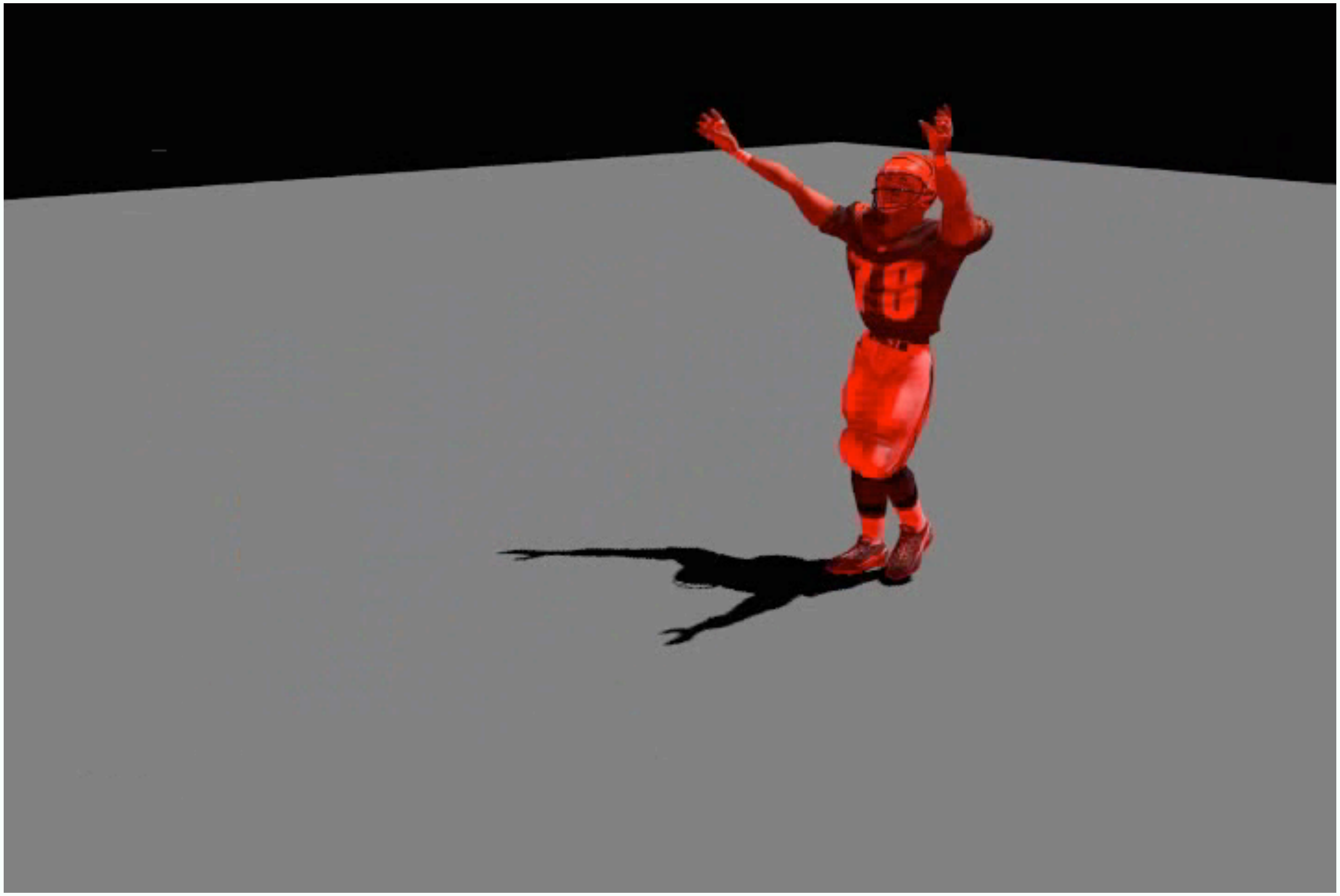

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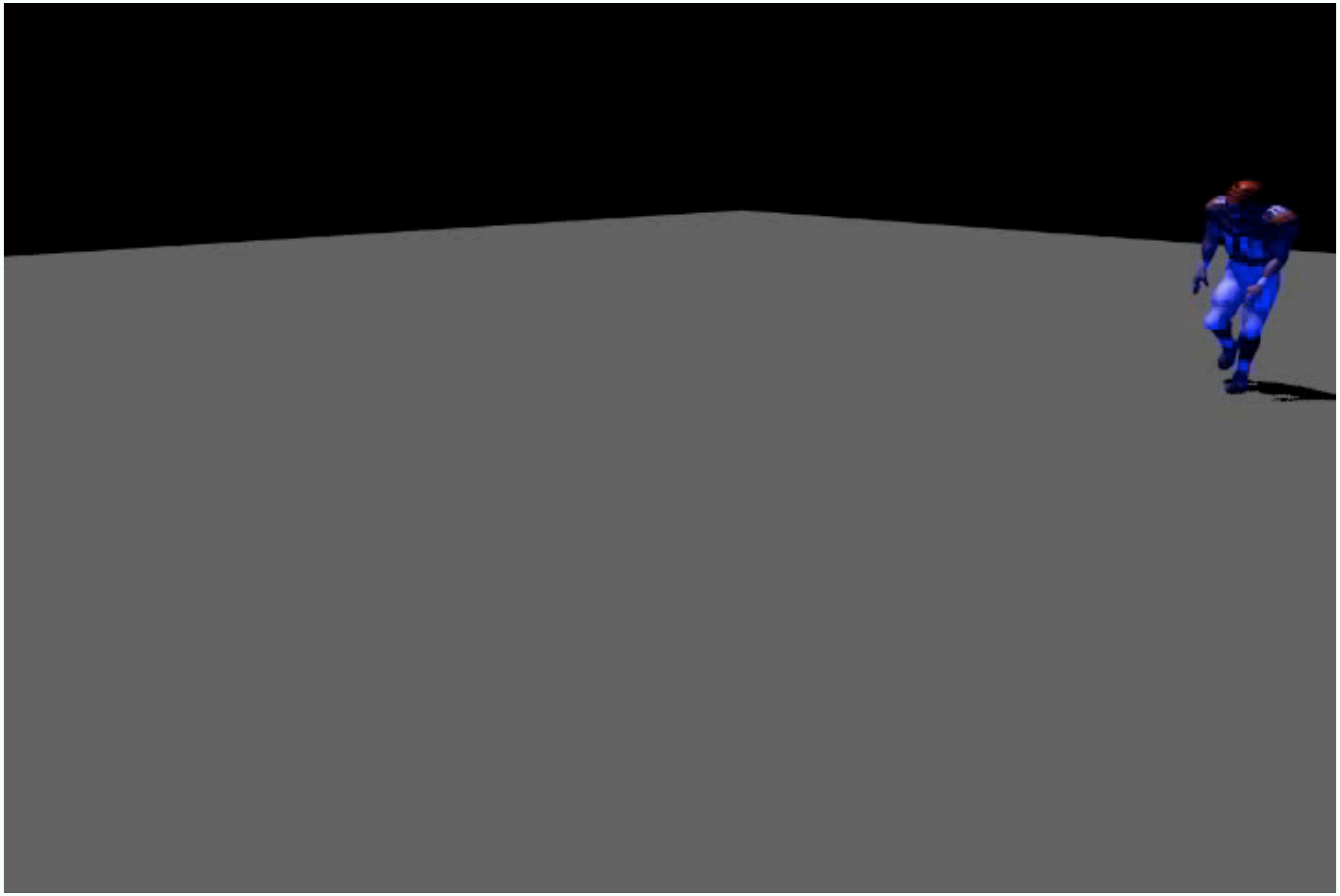

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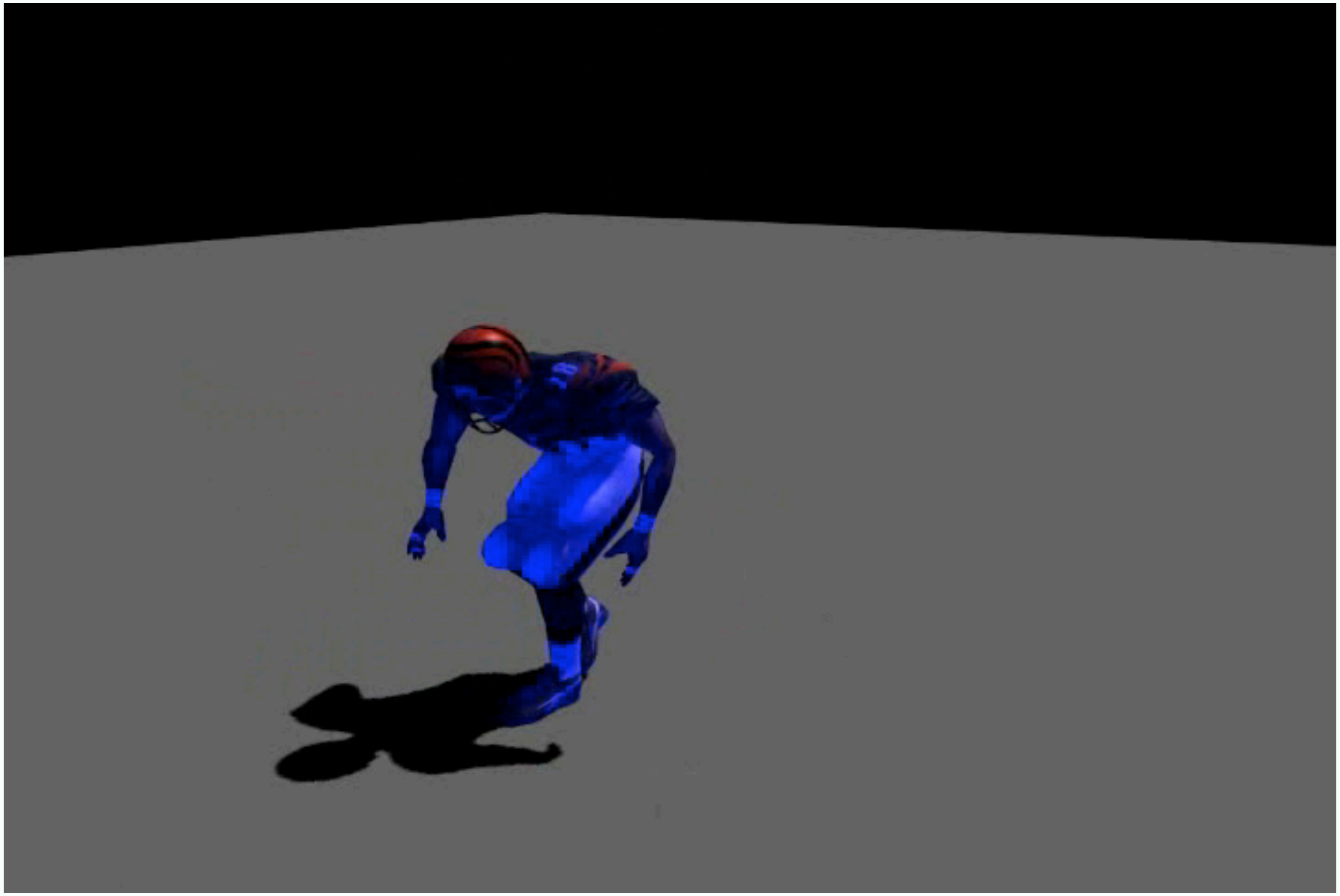


Ikemoto+Forsyth 04

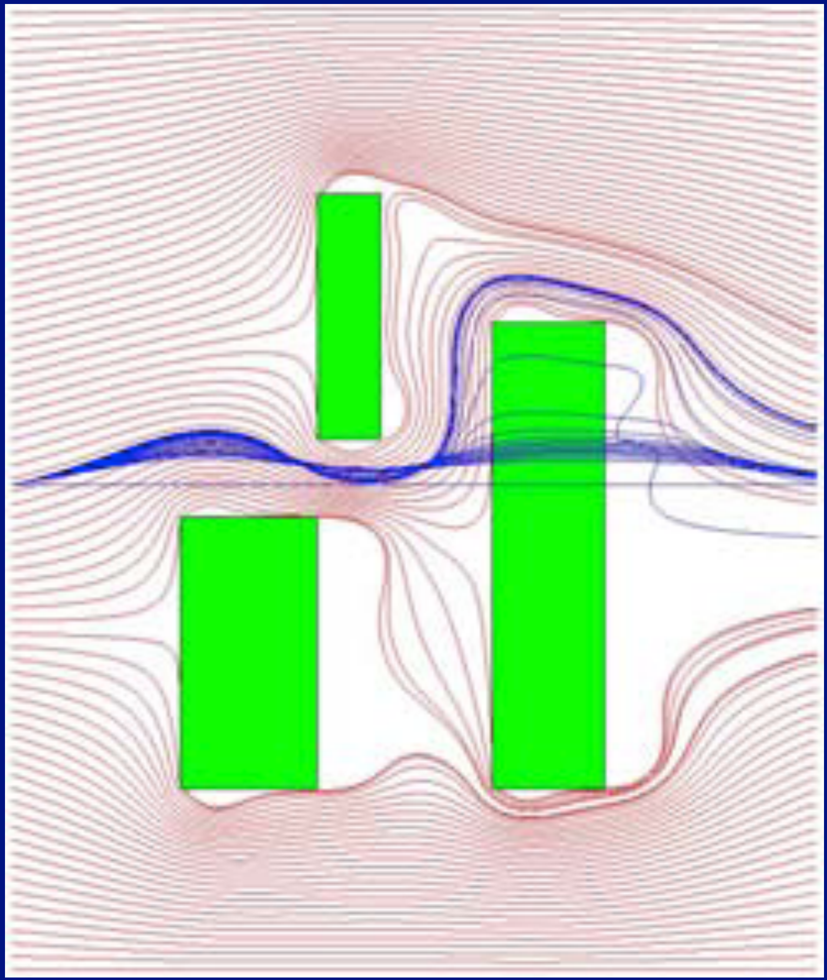
SUBJ	CRS	Section	CRN	Date	Day	Start Time	End Time	Building Room	Exam Type
CS	419	C3, C4	31366, 39734	5/8/2012	T	8:00 AM	11:00 AM	1SIEBL-1103, 1SIEBL-1105	Extra Space

Physically based animation

- General idea
  - take physical models, make assumptions, solve
  - render solution
- Influential areas
  - we've seen
    - particles,
    - collision+ballistic
  - Others
    - fluids (includes gasses)

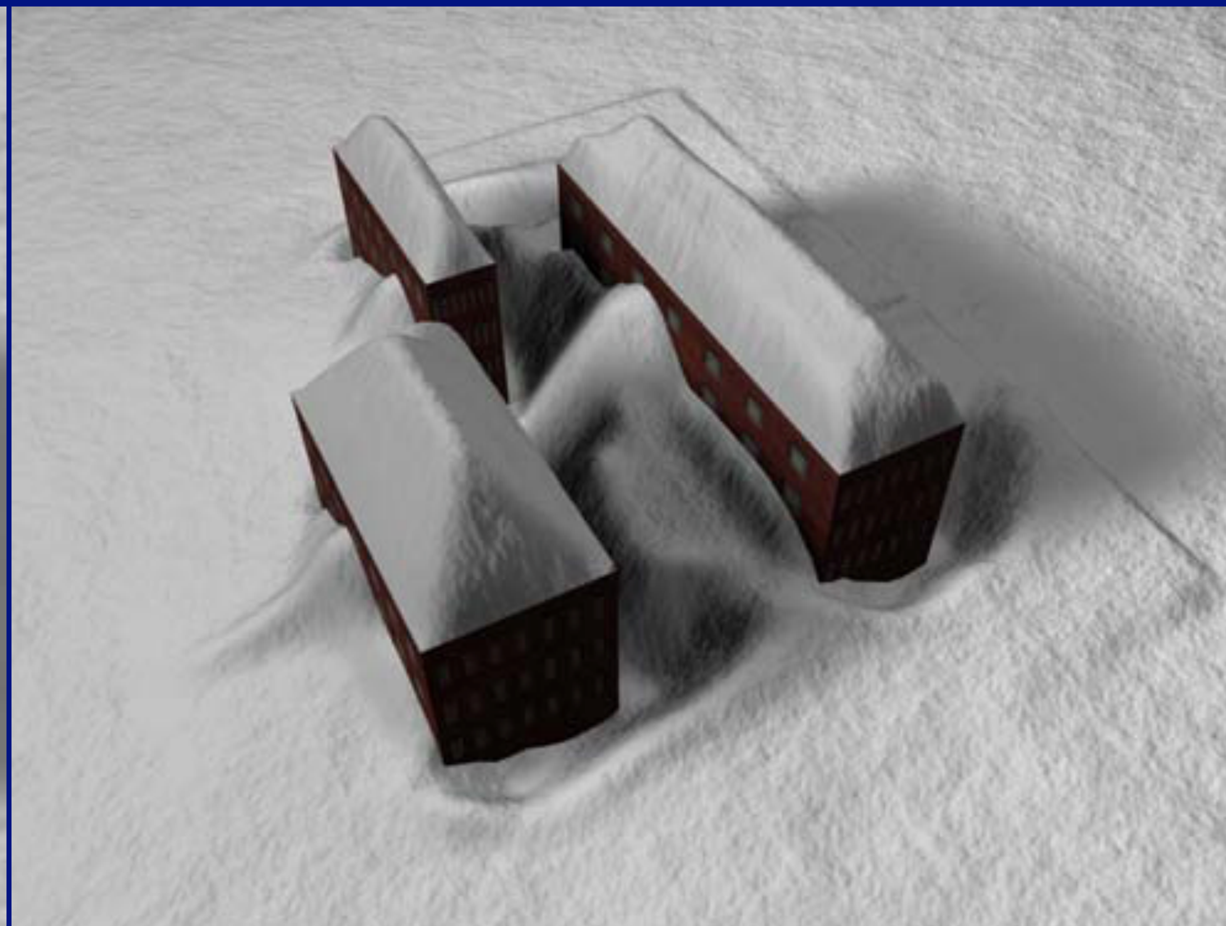
Simple example: Accumulating snow

- Build a fluid simulation
  - Break volume into cells
  - compute velocity in each cell (later!)
- Insert particles
  - on boundary
  - proportional to snowfall, n.v
  - velocity
    - wind velocity
    - gravity term
- Landing cells
  - collect a proportion of their snow
  - return it, if velocity is large
  - slope snow



Feldman O'Brien 2002

Snow

Feldman O'Brien 2002

Incompressible, inviscid moving fluids

- Examples
  - incompressible fluids
    - water; air at low speeds; honey
  - viscous fluids
    - honey; oil
- Important simplifications
  - compressible, viscous fluids are hard to model
  - compressible flow doesn’t happen at low mach numbers
  - compression is important in explosions, but very hard to model
    - and most undesirable in hollywood style explosions
  - “dry water”

Dry water

- Variables
  - u velocity vector
  - P pressure field
  - f force (which could be the result of interactions with particles, etc.)
    - per unit volume
  - rho density

- Dynamics
  - Density x Acceleration = Force/unit volume

$$\rho \frac{D\mathbf{u}}{dt} = \mathbf{f} - \nabla P$$

Dry Water

$$\rho \frac{D\mathbf{u}}{dt} = \mathbf{f} - \nabla P$$

Substitute
$$\frac{D\mathbf{u}}{dt} = \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\nabla\mathbf{u}$$

Rearrange, to get

$$\frac{\partial \mathbf{u}}{\partial t} = -\mathbf{u}\nabla\mathbf{u} - \frac{\nabla P}{\rho} + \frac{\mathbf{f}}{\rho}$$

Dry water

Incompressible $\nabla \mathbf{u} = 0$

- Euler equations
  - Mass is conserved
  - Change of momentum is due to
    - change of pressure
    - external forces

$$\frac{\partial \mathbf{u}}{\partial t} = -\mathbf{u}\nabla\mathbf{u} - \frac{\nabla P}{\rho} + \frac{\mathbf{f}}{\rho}$$

Solving dry water

- Set up a grid
  - values of u, P at grid vertices
- Get intermediate velocity field
  - by taking a small time step, ignoring pressure effects
  - we will choose a pressure field to correct this to be an incompressible flow

$$\frac{\mathbf{u}^* - \mathbf{u}}{\delta t} = -(\mathbf{u} \cdot \nabla)\mathbf{u} + \mathbf{f}$$

$$\mathbf{u} = \mathbf{u}^* - \delta t \nabla P$$

- Correct the intermediate velocity field

$$\nabla^2 P = \frac{1}{\delta t} \nabla \cdot \mathbf{u}^*$$

Example: Suspended particle explosion

- There is hot gas, moving under forces generated by
  - burning
  - momentum
  - changes in pressure
  - etc.
- In the gas, there are particles that
  - move
  - heat and cool
  - radiate
- Render by rendering the particles
  - different colors for different temperatures
  - soot particles are black
  - from 1e6 to 4e6 particles

Feldman, O'Brien, Arikan, 03

Modified dry water

- For an explosion, we must have some fluid expansion
  - at points of detonation
  - we do not want to allow the fluid to expand everywhere,
    - or couple this to the fluid's dynamics
    - pressure waves

$$\nabla \mathbf{u} = \phi$$

- So the pressure update step changes

$$\nabla^2 P = \frac{1}{\delta t}(\nabla \cdot \mathbf{u}^* - \phi)$$

Heat

- The fluid has heat
  - which is lost by radiation, etc. and gained from particles
- so do particles
  - generate heat by burning
    - which drives the temperature of the particle
      - which drives the transfer of heat into the fluid

Temperature field model

- Fluid temperature
  - temperature grid

$$\frac{DT}{dt} = -c_r \left(\frac{T - T_a}{T_{\max} - T_a} \right) + c_k \nabla^2 T + \frac{1}{\rho c_v} \frac{\partial H}{\partial t}$$

Heat lost by radiation

Heat diffusion
(in model, c_k is set large)

Heat gained from hot particles moving around

Particles in the fluid

Particle location

Forces on particle,
including gravity

- Move

$$\frac{d^2\mathbf{x}}{dt^2} = \frac{\mathbf{f}}{m}$$

- Heat

$$\frac{dY}{dt} = \frac{1}{c_m}\frac{\partial H_p}{\partial t}$$

Particle temperature

Particle fluid interactions

- Drag on particle
  - force in opposite direction applied to fluid
  - low mass - no drag

$$\mathbf{f} = \alpha_d r^2 (\mathbf{u} - \frac{dx}{dt}) \parallel (\mathbf{u} - \frac{dx}{dt}) \parallel$$

Particle radius

- Thermal exchange
  - heat transfer to a particle from fluid
  - transfer goes both ways
  - T - fluid temperature field

$$\frac{\partial H_p}{\partial t} = \alpha_h r^2 (T - Y)$$

$$\frac{\partial H}{\partial t} = \alpha_h r^2 (Y - T)$$

Particle behaviour

- Particles burn
  - Simplified combustion
    - combustion is independent of oxygen
    - independent of temperature
    - products do not depend on temperature
- Model
  - Particle ignites when its temperature exceeds a fixed threshold
  - fixed amount of fuel
  - burn at a fixed rate (burn rate)
  - dies when its mass is zero
- Products
  - Heat
  - Gas

$$\frac{dm}{dt} = z$$

Products of combustion

- Heat

$$\frac{\partial H_p}{\partial t} = b_h z$$

Add this term to dH_p /d t

- Gas

$$\Delta\phi = \frac{1}{V} b_g z$$

- Soot
  - this builds up to a threshold - then a soot particle is released.

$$\frac{ds}{dt} = b_s z$$