Human Performance Modeling:
Route Selection and Action Selection

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Deadlines

- Final Exam (take-home), out on Mar 25th, due on Apr 1st
- No class on Apr 27th
- Paper Presentations: Apr 1-17th (please send me your preferred presentation date by Friday!)
- Homework due on Apr 11th
- Final Project Writeup Apr 24th
- Final Project Demo: Apr 23rd (time TBD)

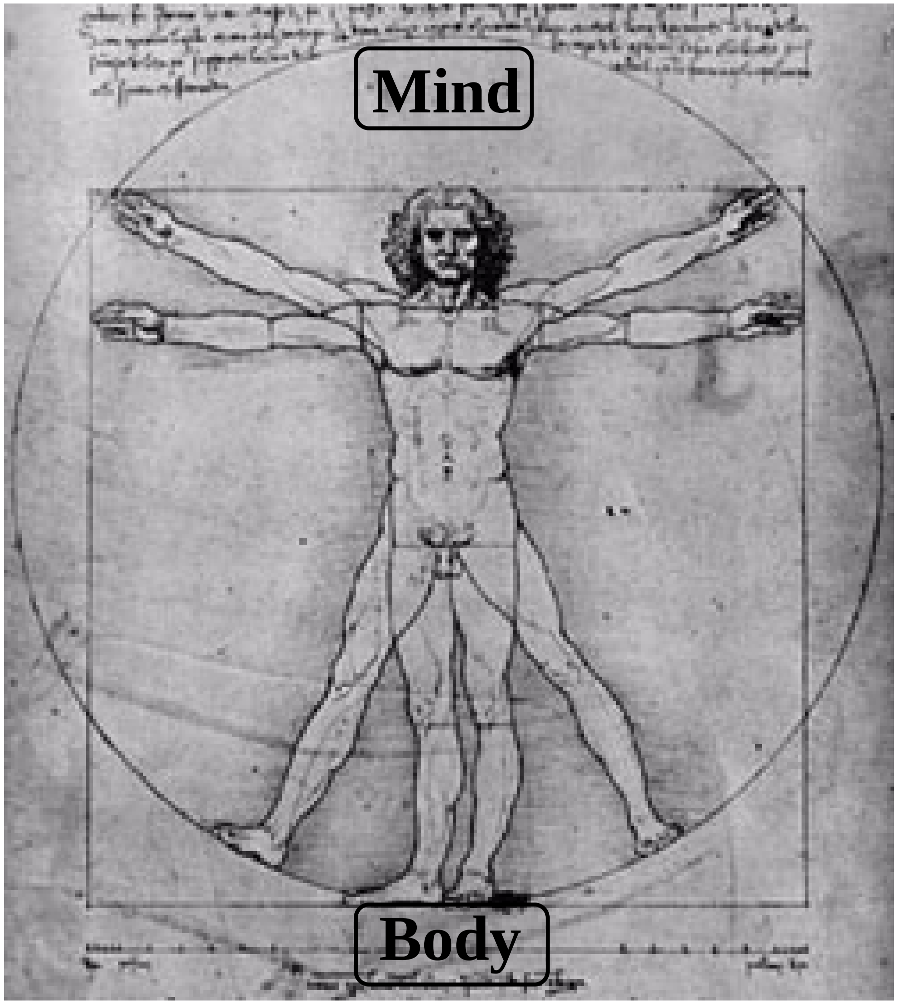
Overview

- Why model humans?
- Route selection model [Fajen & Warren, 2003]
- Action selection based on physical capabilities [Sukthankar et. al 2004]

Why model humans?

- Potential applications:
  - Computer games
  - Training simulations
  - Assistive technologies
- Interesting problems:
  - Creating human-like teammates and opponents
  - Assisting humans by predicting future actions

Intelligent Virtual Human



Cognitive Model (SOAR, ACT-R)

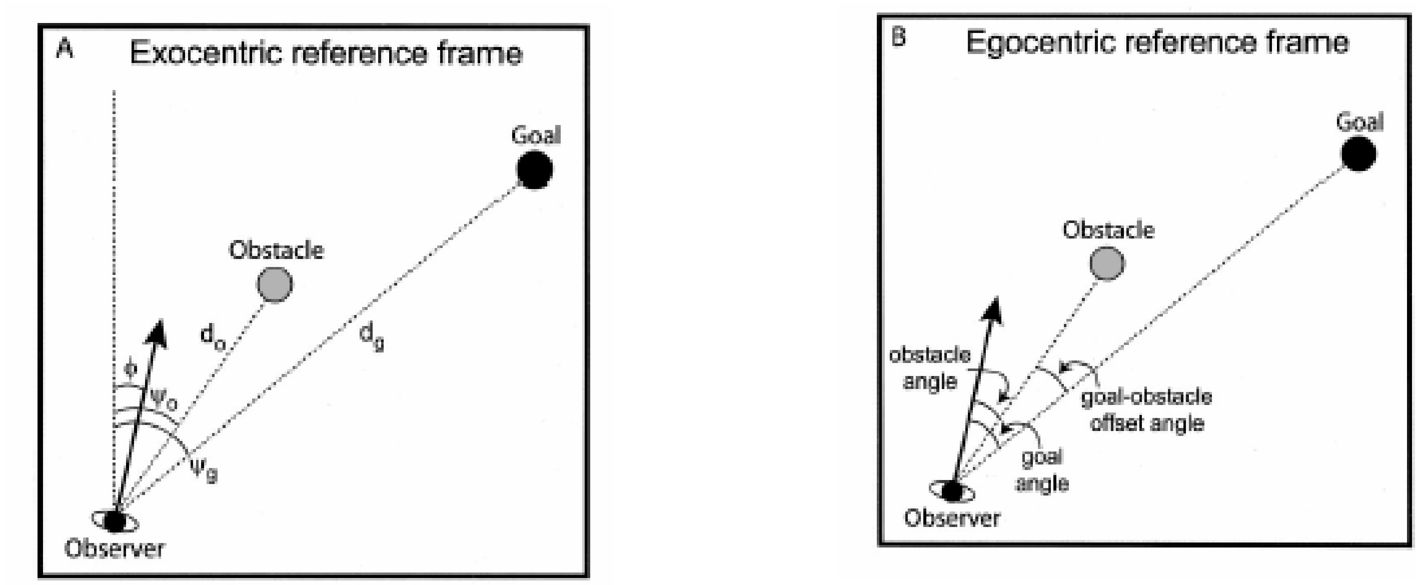
Physical Reasoning

Human Figure Animation

Route Selection [Fajen & Warren, 2003]

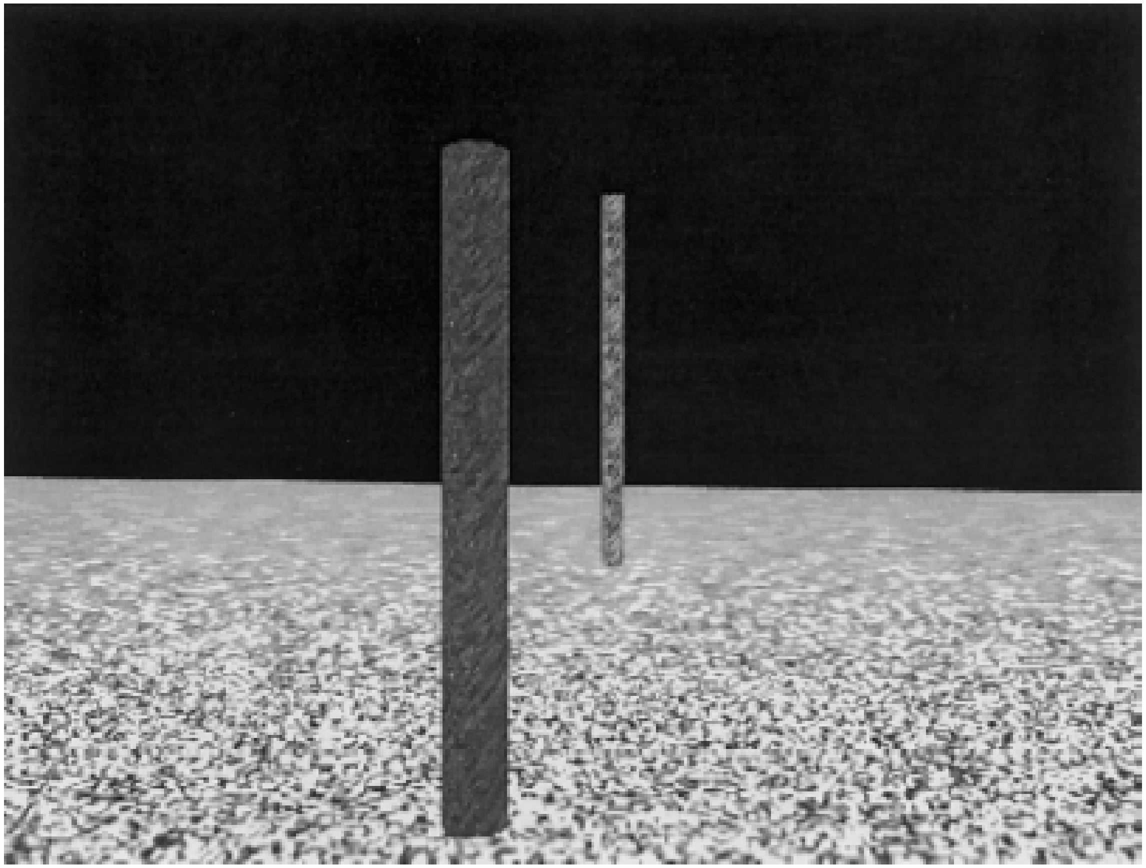
- Contributions
  - 2^{nd} order dynamical model of human route selection towards stationary goals and around stationary obstacles
  - Predicts whether human will go to the left or right of an obstacle
  - Implemented on a robotic system [Huang et. al 2004]

Coordinate Frames

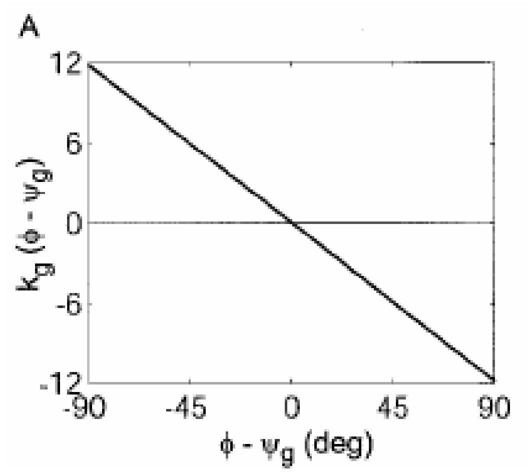


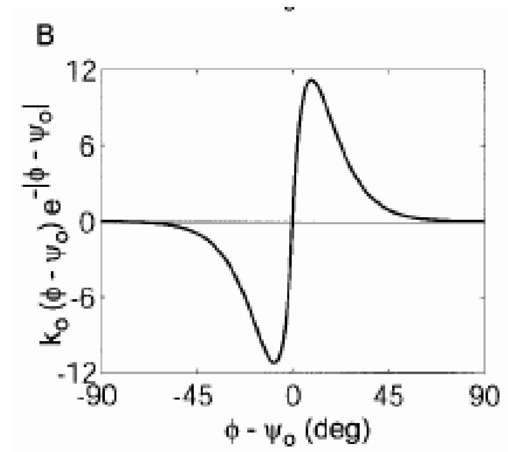
Egocentric goal angle can be calculated from perceptual information available to humans (optic flow and the locomotor axis).

VENLab



Steering Model



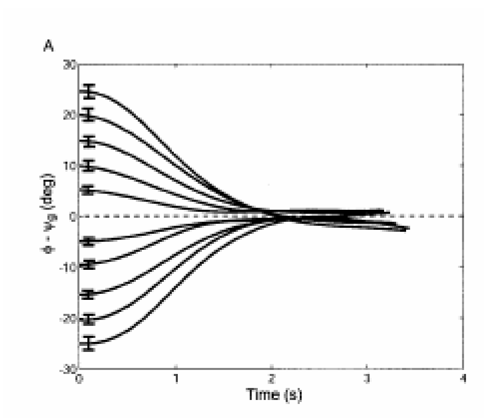


$$\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1 d_g} + c_2) + k_o(\phi - \psi_o)e^{-c_3|\phi - \psi_o|}(e^{-c_4 d_o})$$

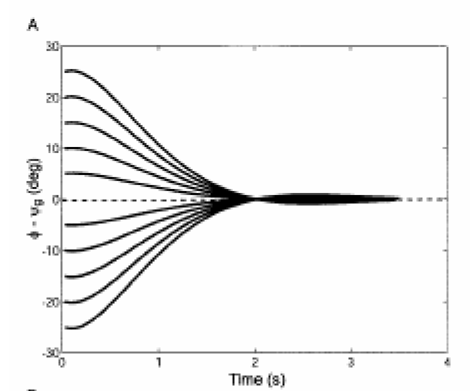
Parameter Fitting

	Human	Robot	Description
b	3.25	0.87	Damping coefficient
k_g	7.5	0.75	Goal potential stiffness
c_1	0.4	0.3	Decay with goal distance
c_2	0.4	0.4	Goal distance decay limit
k_o	198	30	Obstacle potential stiffness
c_3	6.5	6.5	Decay with obstacle angle
c_4	1.6	0.7	Decay with obstacle distance

Table 1: Model Parameters from our implementation compared with values fit to human data.



Human



Model

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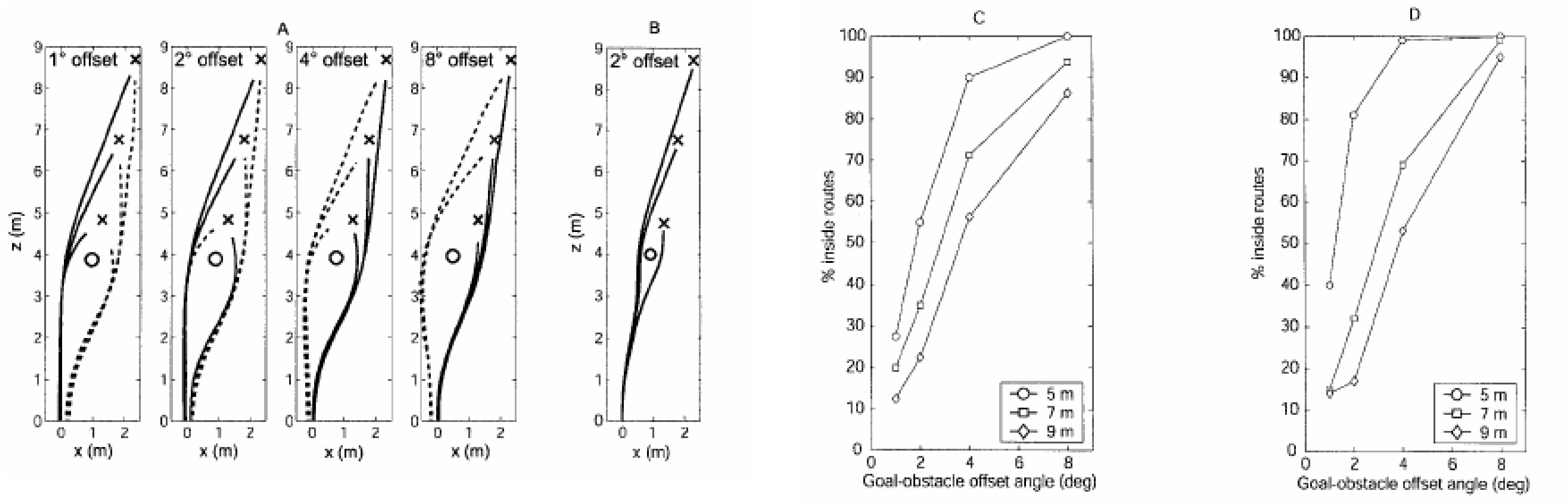
Experiments

- Steering towards a single goal
  - Effects of goal angle
  - Effects of goal distance
- Avoiding an obstacle
  - Effects of obstacle angle
  - Effects of obstacle distance
- Route selection with one goal and one obstacle
  - Effects of offset angle
  - Effects of goal distance

Inside vs. Outside Routes



Note in these experiments the human subject is already moving when the goal and obstacle appear. Outside routes are closer to the direction of the human's original heading.

D shows the effects of adding noise to the perceptual variables and model parameters.

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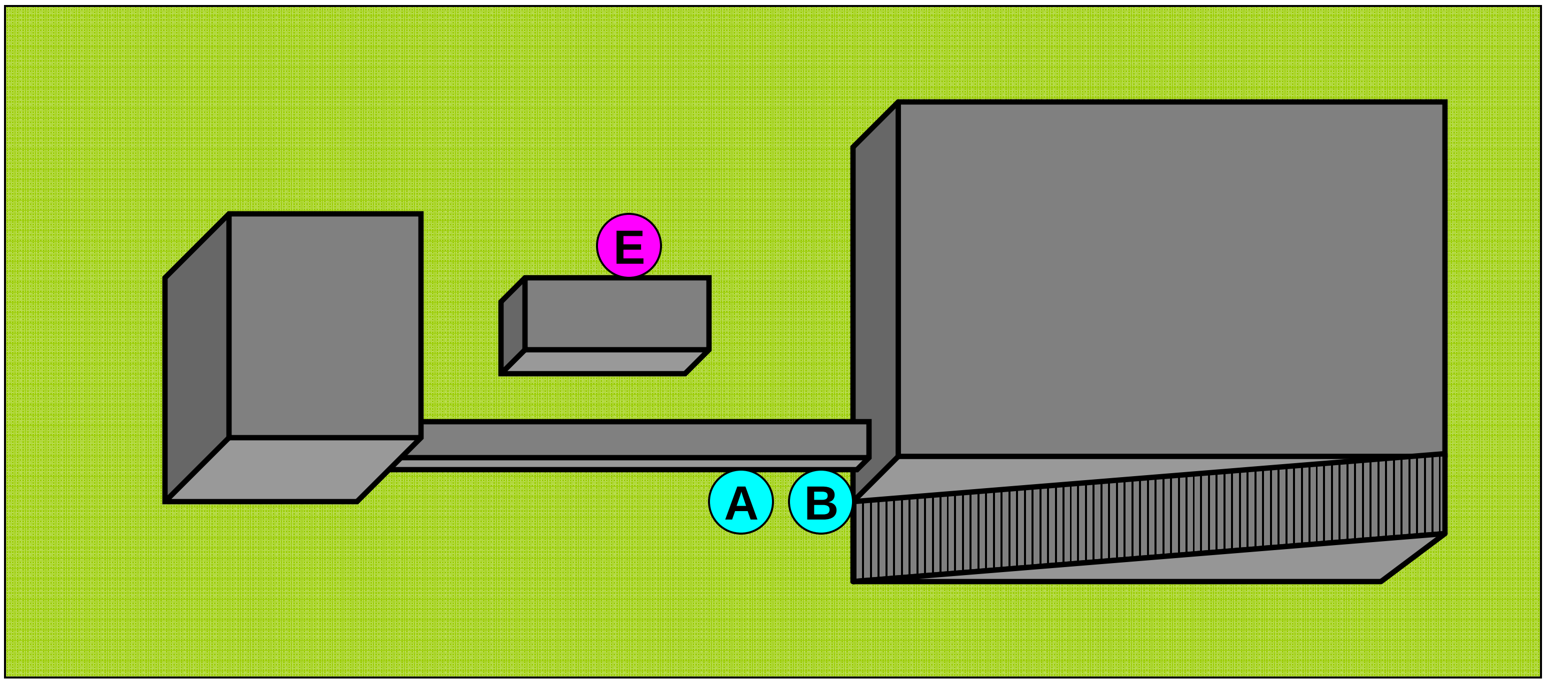
Summary

- Strengths
  - Robust to parameter and sensor error
  - More resistant to local minima problems than other potential field methods
- Limitations
  - Treat goals and obstacles as point sources
  - Assumes constant translational velocity
  - No clear justification given for the functions used in the model

Action Selection based on Physical Capability Modeling [Sukthankar, Mandel, Hodgins, Sycara, 2004]

- Goals
  - Incorporate information about agent's physical capabilities into planning
  - Develop model that's easy to generalize to new physical activities
  - Tailor the model for specific human subjects

Improving Planning Effectiveness



A and B plan to move into a flanking configuration.
Which flanking position can be achieved most rapidly?

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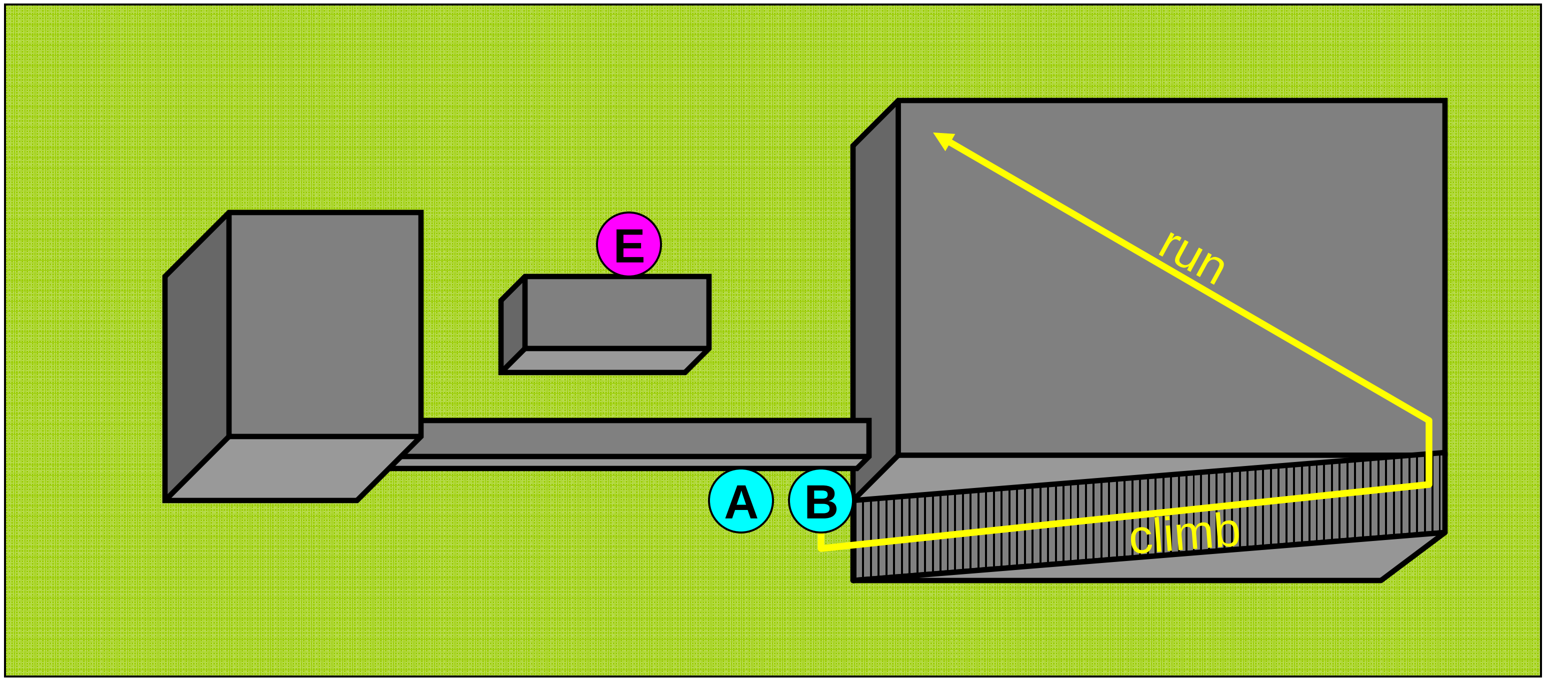
Improving Planning Effectiveness



Plan 1: A maintains fire on E while B climbs and runs to the right flank position before opening fire

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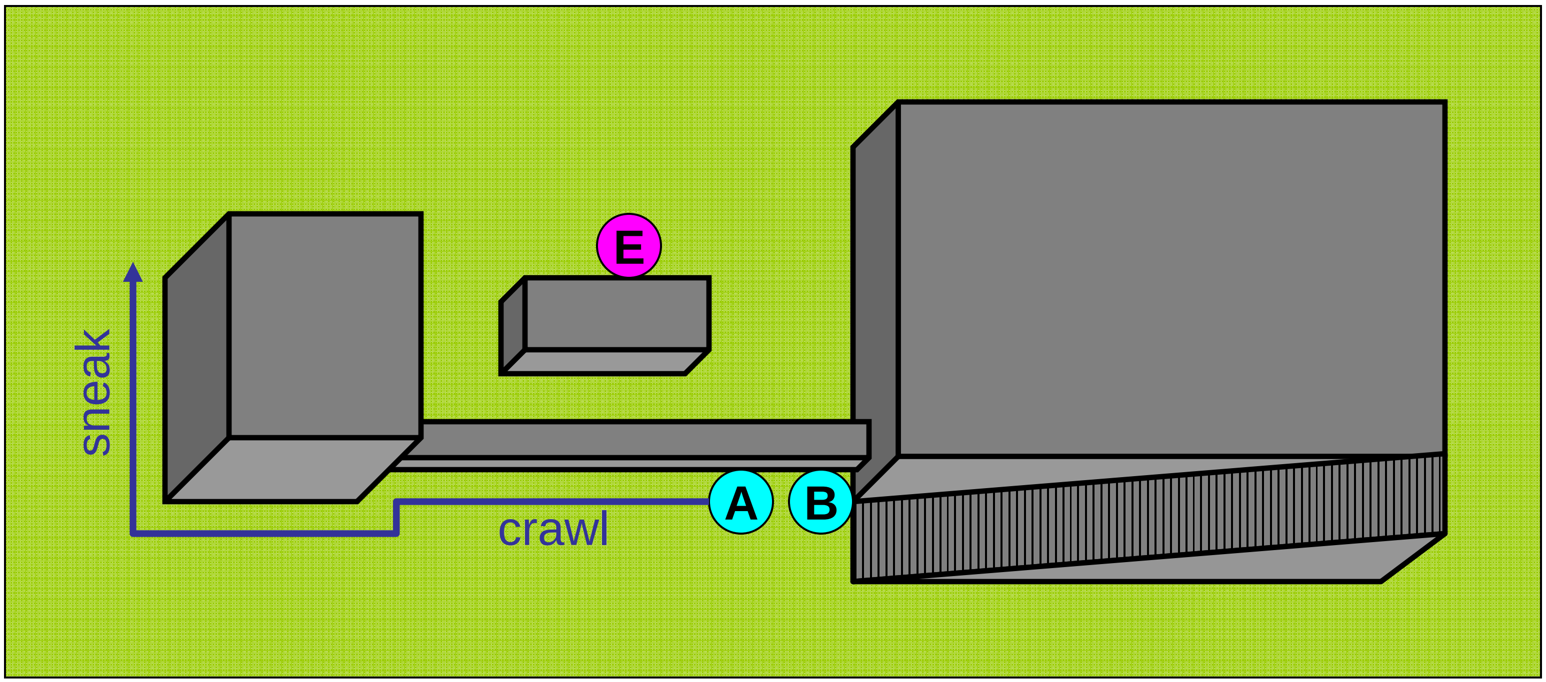
Improving Planning Effectiveness



Plan 2: B maintains fire on E while A crawls behind the cover of a low wall and sneaks to the left flanking position

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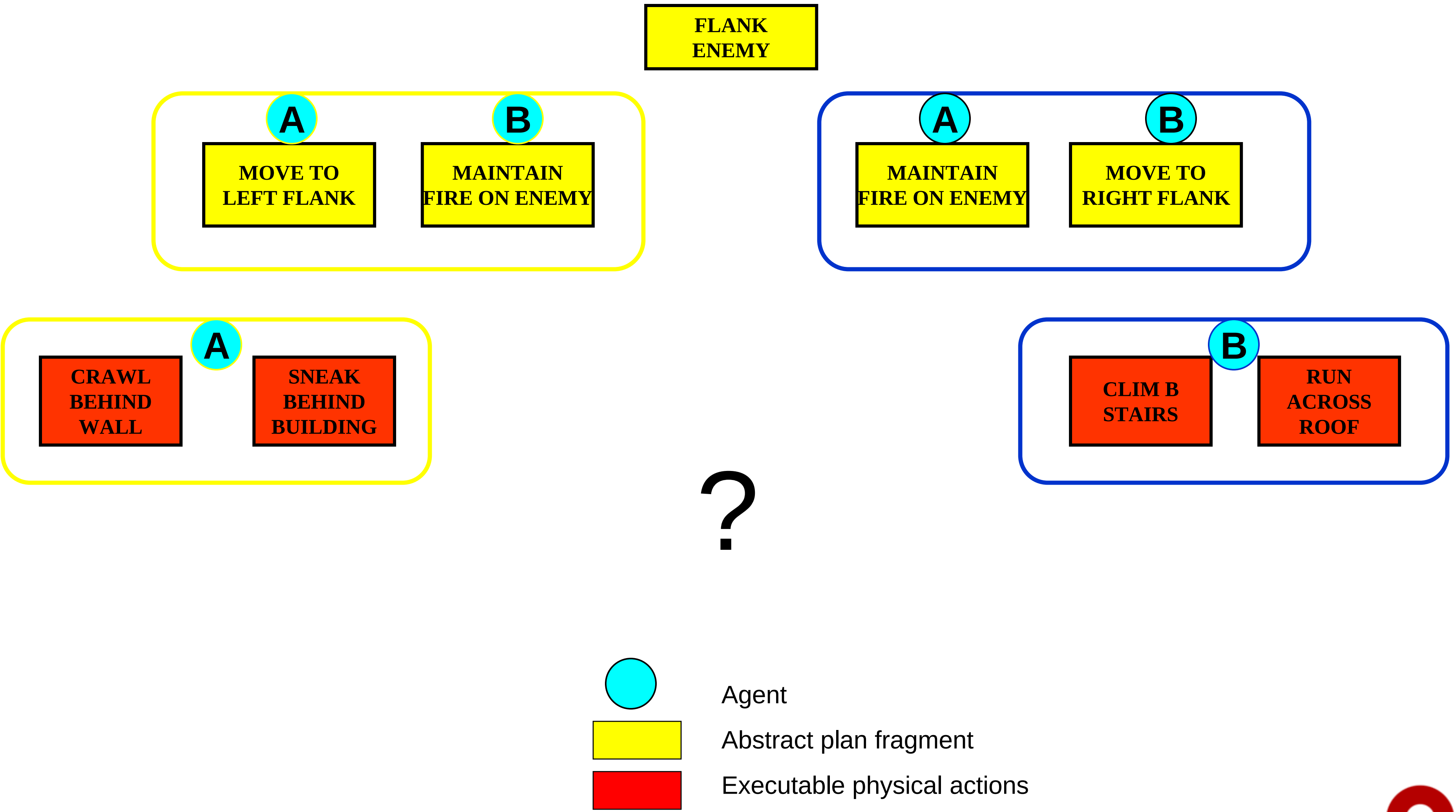
The Agent's Dilemma



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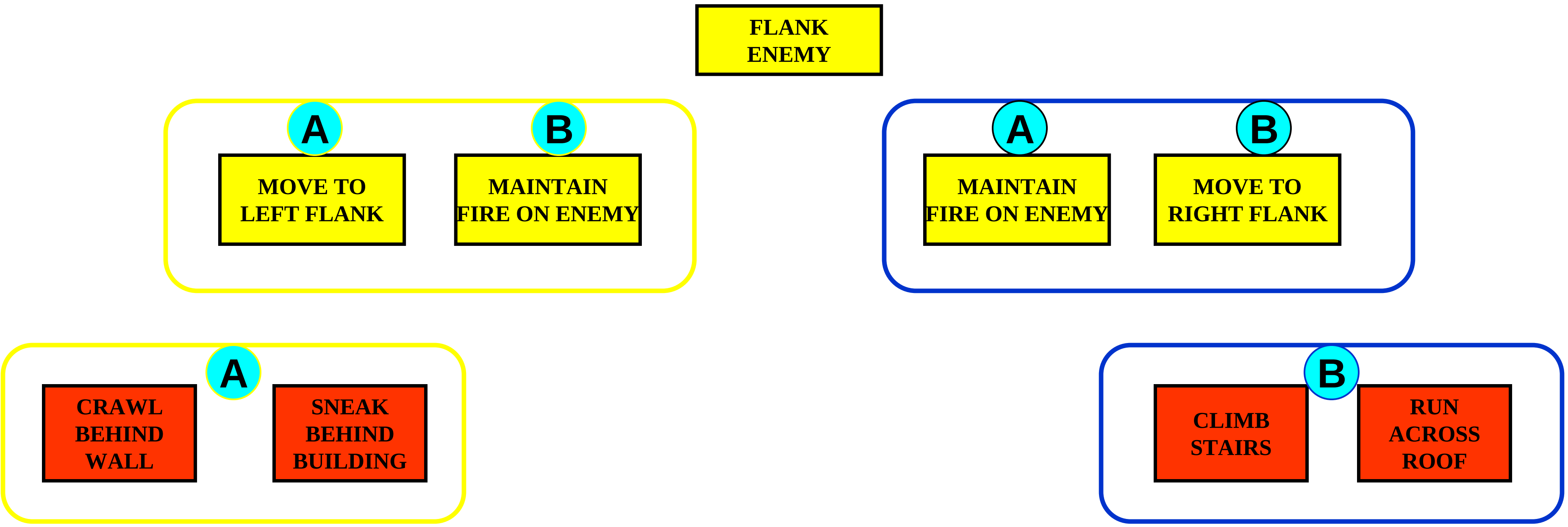
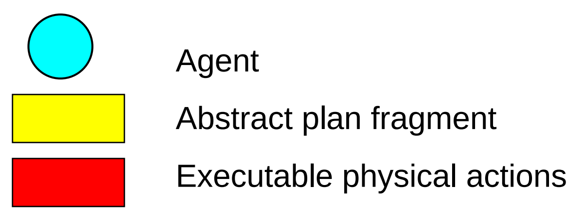
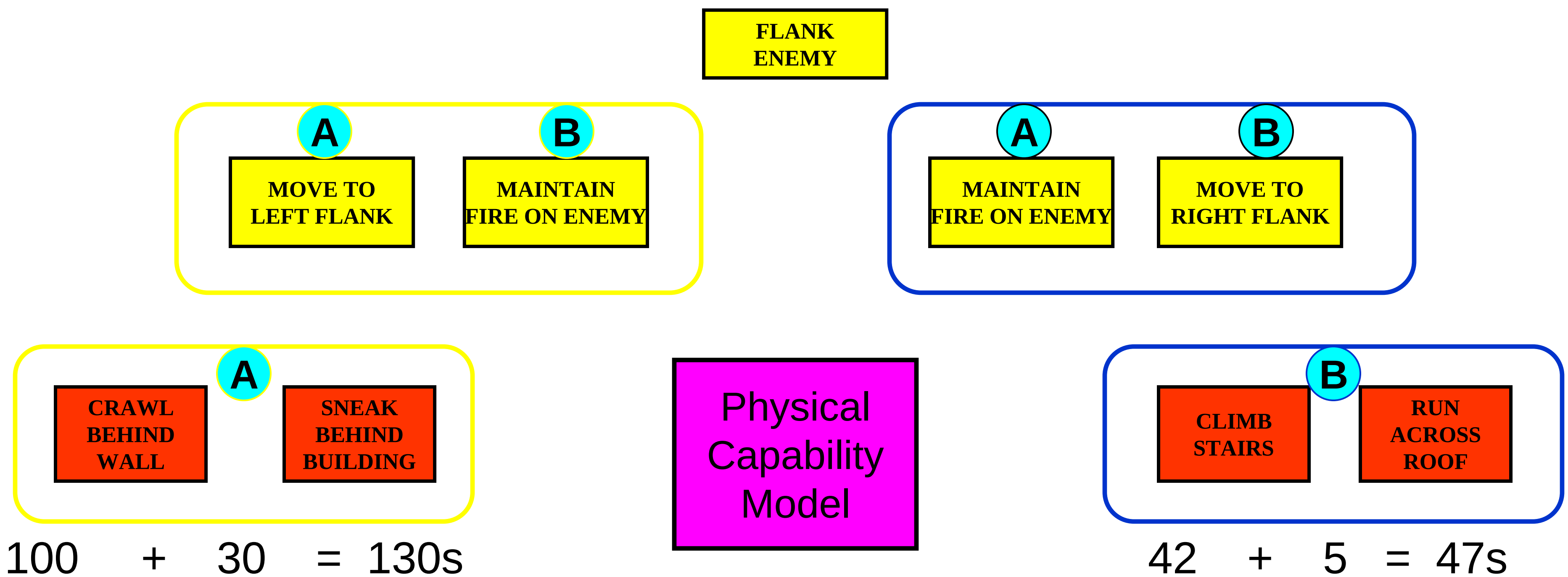
Solving the Agent's Dilemma



Intuition: in a dynamic domain it is often better to select a plan that executes rapidly before the situation changes. Which plan requires less time to complete?



Solving the Agent's Dilemma



The physical capability model enables us to determine that the right flank plan will complete faster.

Agent

Abstract plan fragment

Executable physical actions

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Physical Capability Model

Physical capability model allows the agent to reason about its physical abilities prior to execution time.

Our framework for constructing a physical capability model:

- Capture motion data from human subjects
- Construct a motion graph that enables rapid generation of animation sequences for each behavior
- Score animation sequences based on elapsed time
- Precompute a cost map that expresses the variation in time cost for executing a particular behavior

During planning use the model to select between a set of otherwise equivalent goal-achieving behaviors.

Limitations of Existing Models

- Simple heuristics (fewest steps, shortest distance) are inadequate for complicated scenarios.
- Refined biomechanical models have been built to accurately model human physical capability but are difficult to incorporate into planning.
- Data used for biomechanical models must be specially gathered and can't easily be reused for other applications.
- Specific models for standard behaviors (walking, running) have been built but do not easily generalize to other physical behaviors (crawling, dribbling, sneaking).

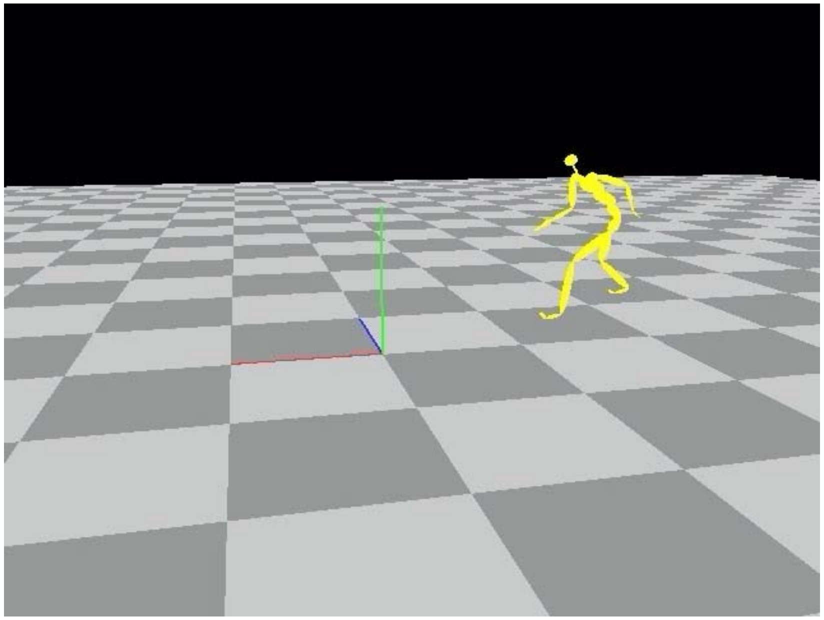
Related Work

- Animation
  - Motion graph construction [Kovar, Gleicher, Pighin 2002]
  - Analyzing motion graphs for data coverage [Reitsma & Pollard 2004]
- Psychology & Human Behavior Modeling
  - Human locomotion models [Fajen & Warren 2003]
- Software agents
  - Creating virtual humans for team training [Rickel & Johnson 2002]

Motion Capture

Human subjects equipped with fiducial markers on canonical joint and skeletal positions, perform movements in the CMU Motion Capture Lab.

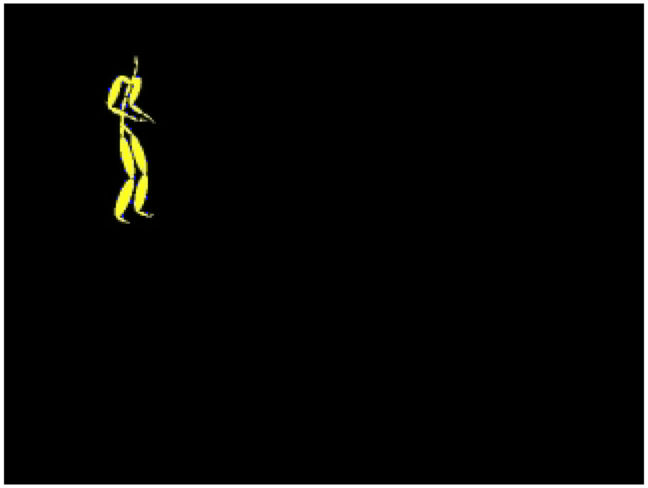
Motion Capture



Measure motion recorded from a human subject and apply it to an animated character.

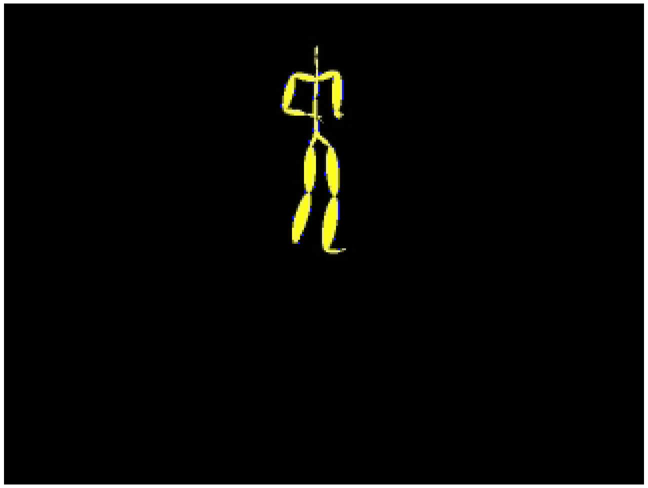
Physical Behaviors (Basketball)

Defending (side to side)



Drive (with fake out)

Dribble and spin



Pivoting

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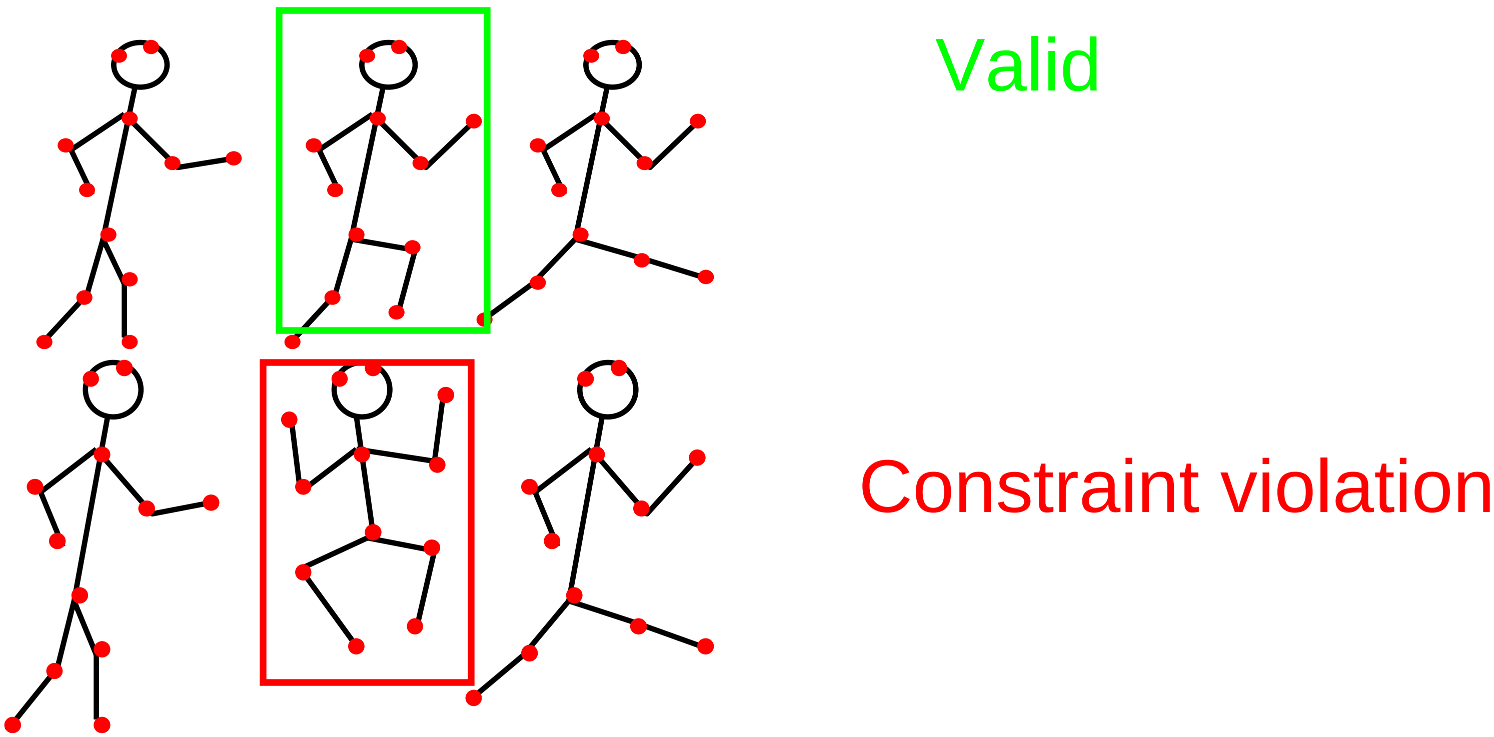
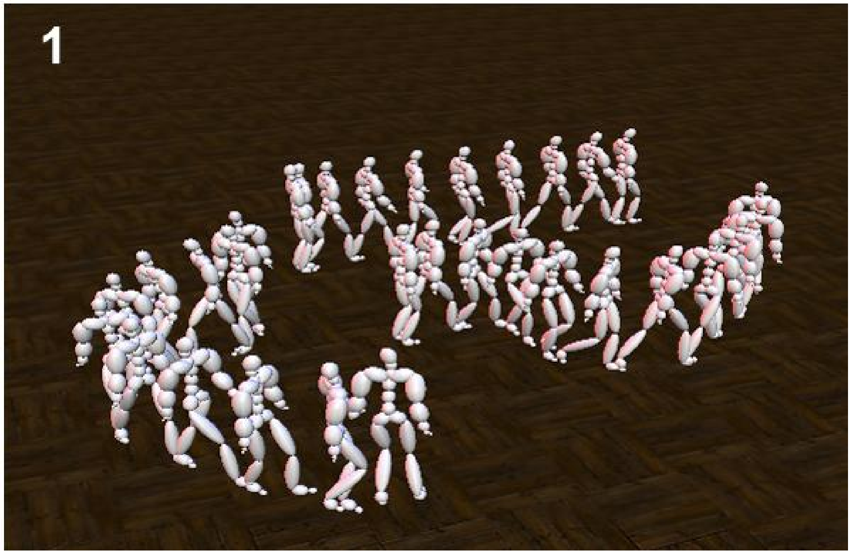
Motion Capture Sequence

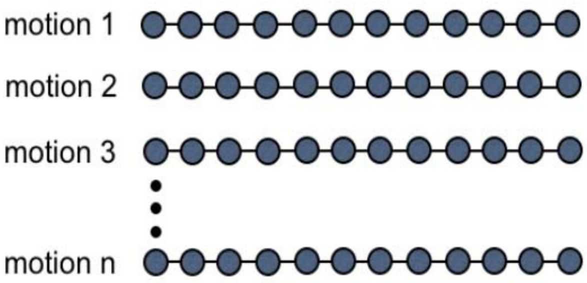
A valid motion capture sequence preserves pose and velocity constraints between frames.



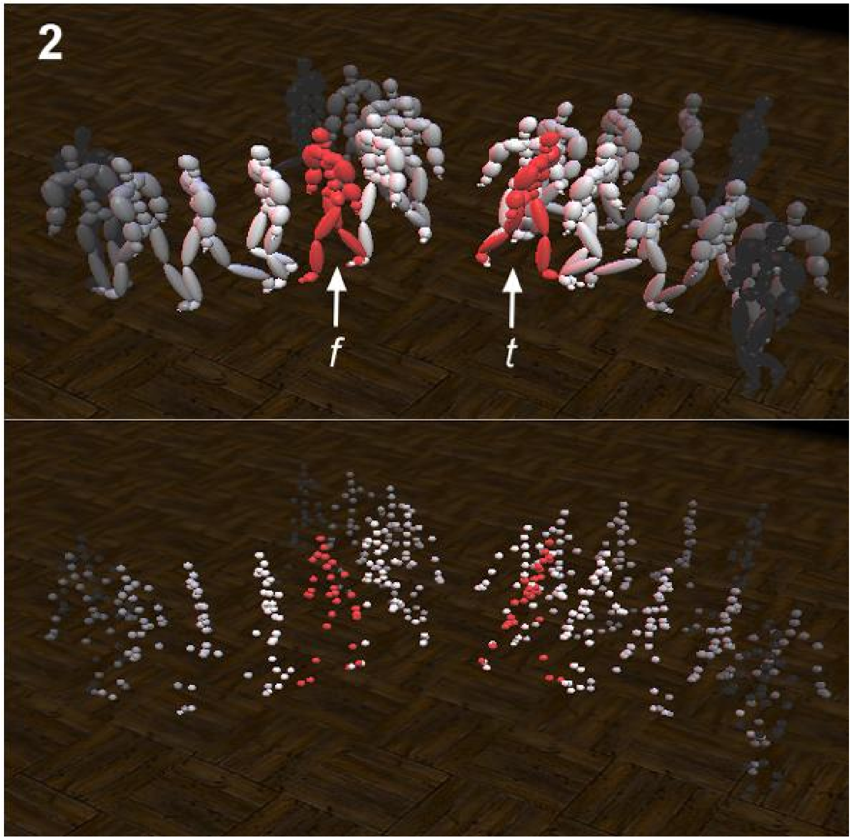
A motion capture graph [Kovar et al, 2002] enables generation of novel, valid sequences from a small set of human data. Synthesized sequences are different from the ones in the initial set but do not violate constraints.

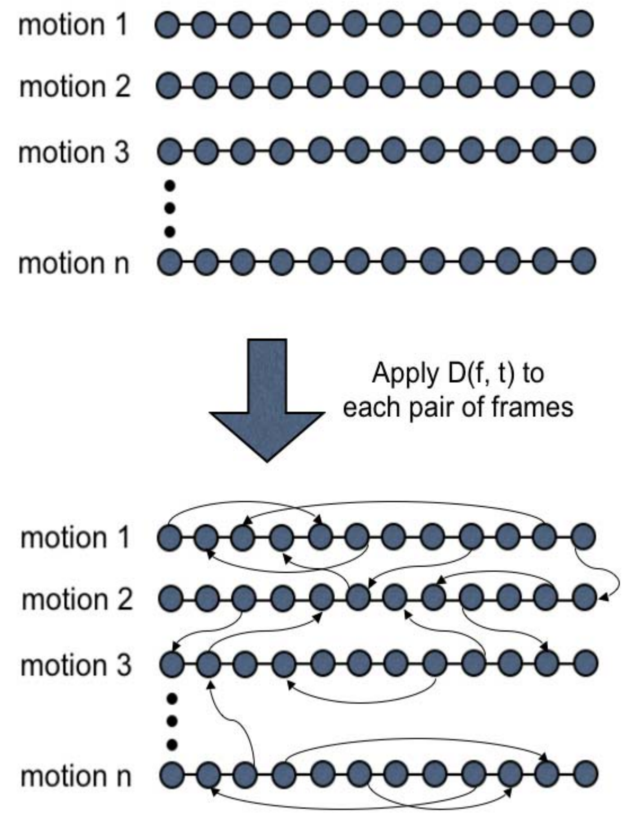
Constructing the Graph





Constructing the Graph

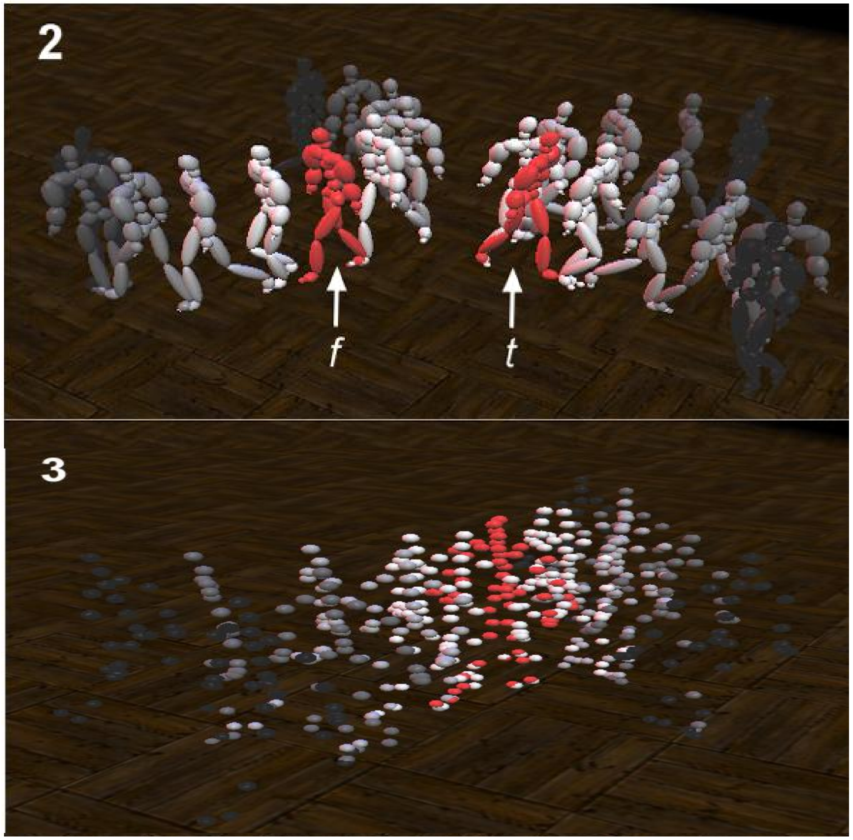


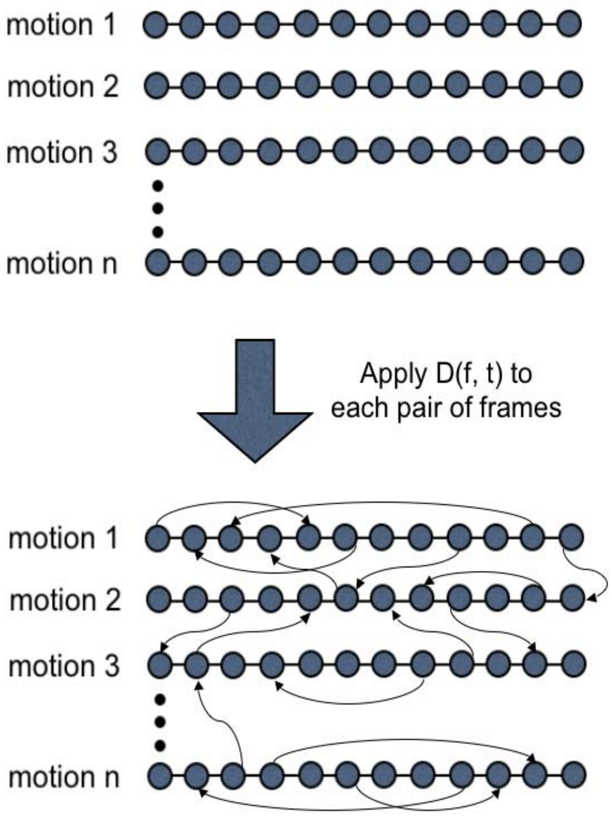


Distance metric

$$D(f,t)=\sum_{i=0}^{WS}\sum_{j=0}^{J} w_j \, \| p(f+i,j) - T(f,t)p(t+i,j)) \|^2$$

Constructing the Graph





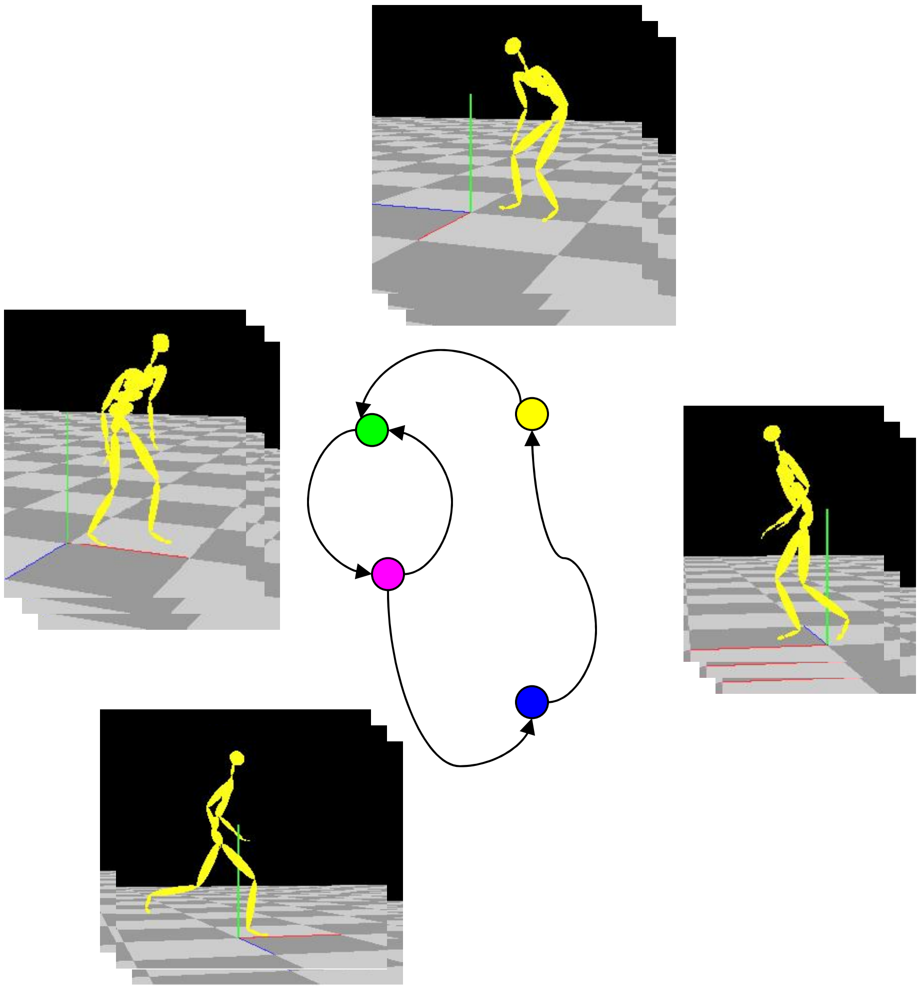
Apply transformation T(f,t) before checking sum-squared distance

Analyzing the Motion Graph

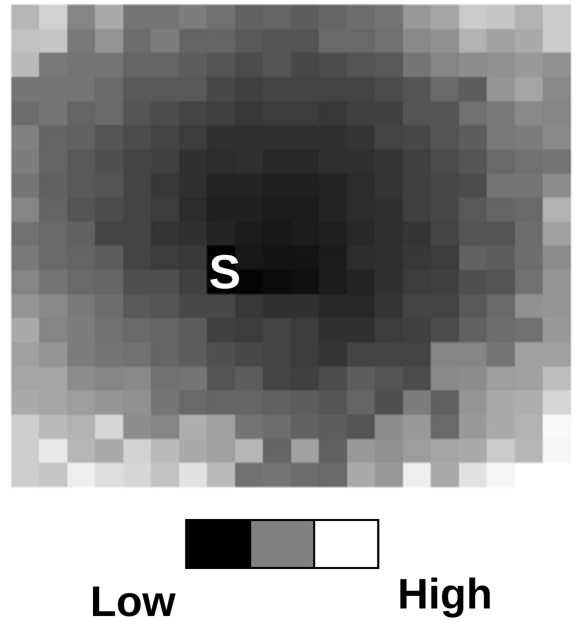
- Implicitly, the motion graph is a model of human physical behavior specialized for the rapid generation of lifelike animations.
- Idea:
  - Use the motion graph to generate many exemplars of human action sequences.
  - Evaluate time cost required to perform each sequence.
- Advantage:
  - Motion graph allows the construction of sequences that the human never actually performed but is plausibly capable of doing.

Converting Motion Graph to Cost Map

Joint Position Space

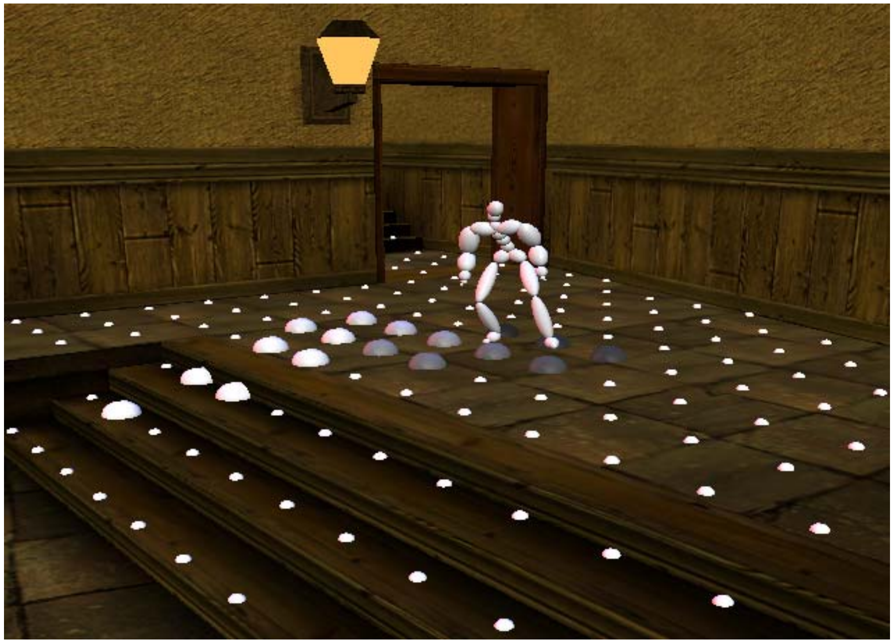


X-Y Space



Cost = frame count

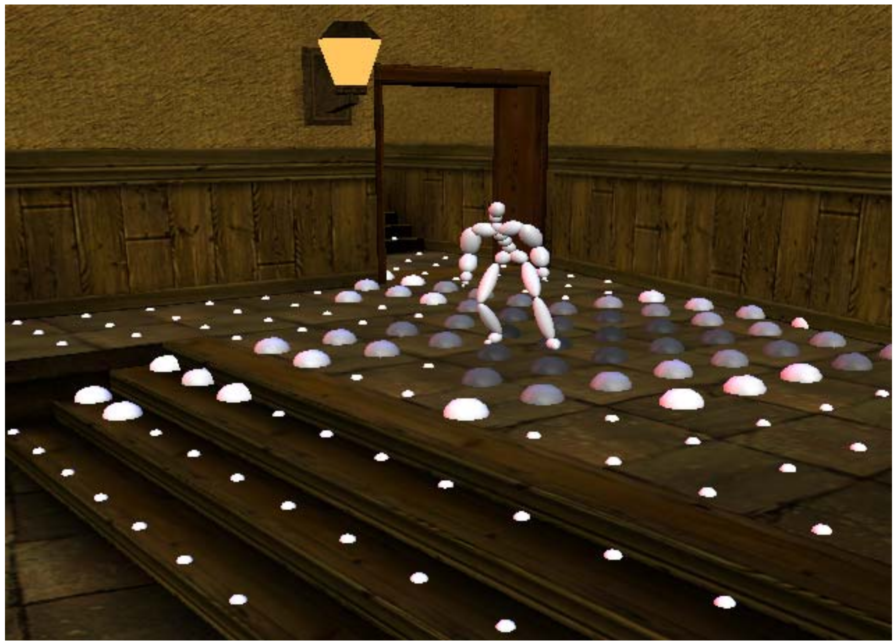
Simulator View (~100 iterations)



Simulator stochastically searches the motion graph to build a cost map of the environment

Unexplored
High cost (slow)
Low cost (fast)

Simulator View (~1000 iterations)



Simulator stochastically searches the motion graph to build a cost map of the environment

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High cost (slow)
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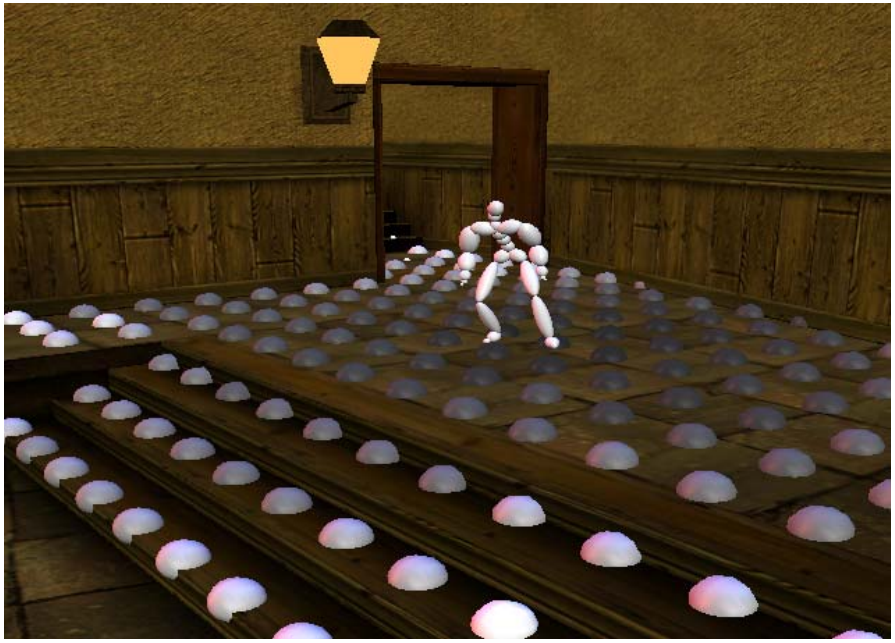
Simulator View (~10000 iterations)



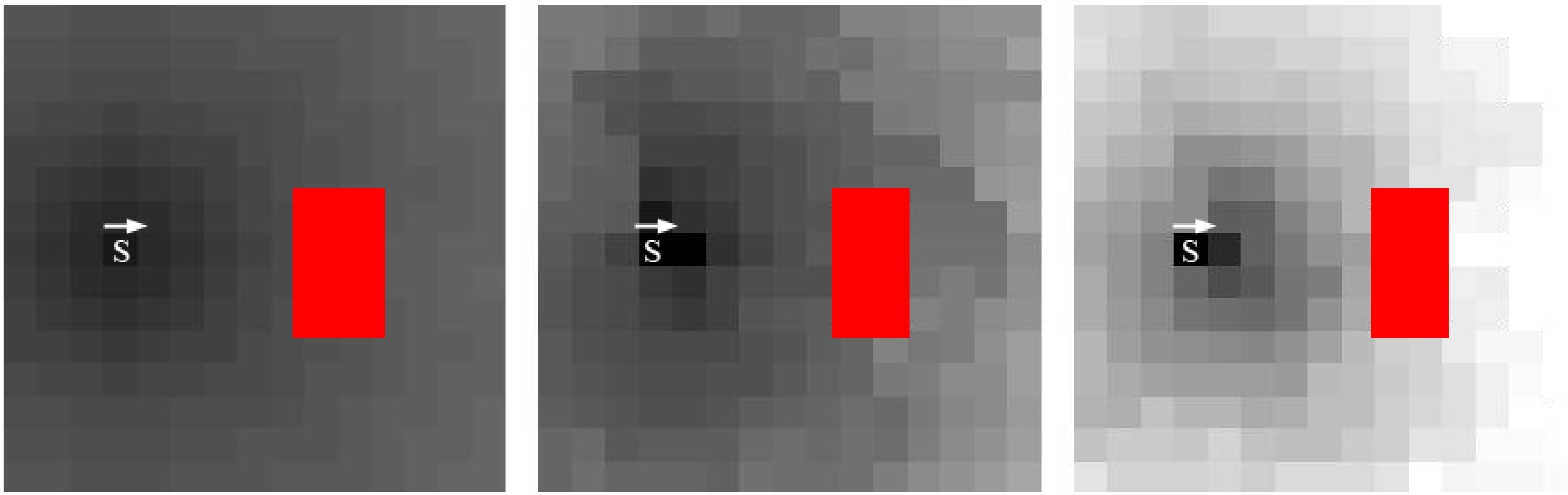
Simulator stochastically searches the motion graph to build a cost map of the environment

Unexplored
High cost (slow)
Low cost (fast)

Model Limitations

- Assumptions:
  - The motion graph is a good model of the physical capability of the subject.
  - Motion sequences of behaviors that are implausible or difficult to execute cannot be constructed without incurring a substantial penalty in the cost function.
- Physical capability model requires:
  - A complete basis set of data for every behavior that the agent is allowed to execute
- Does not accurately model:
  - Time dependent effects such as fatigue and endurance.

Behavior Cost Maps

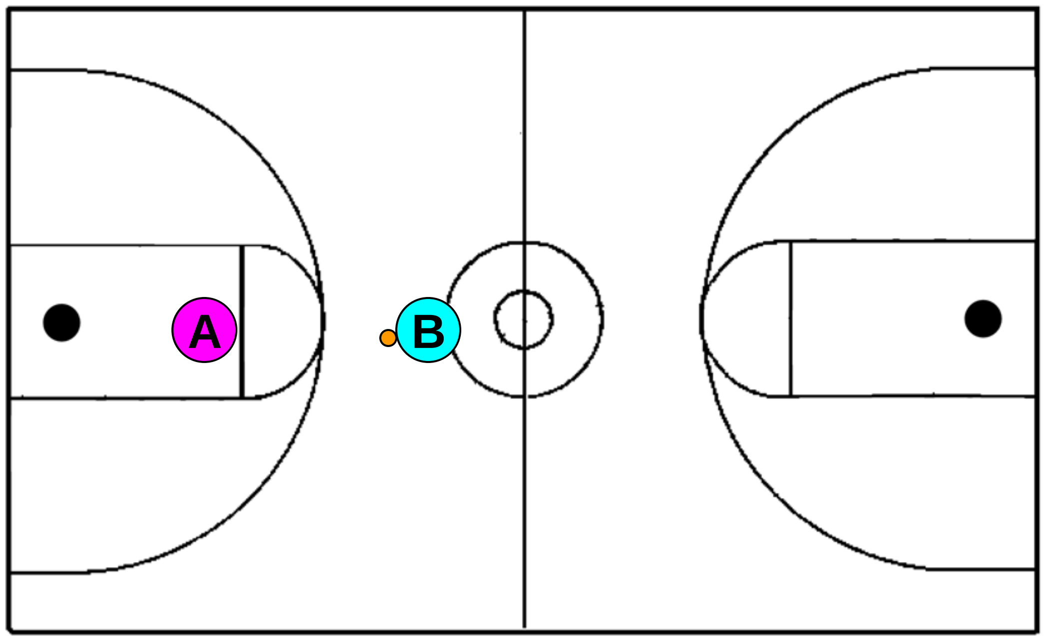


Distance-based   PCM (Running)   PCM (Sneaking)

Fast **Slow**

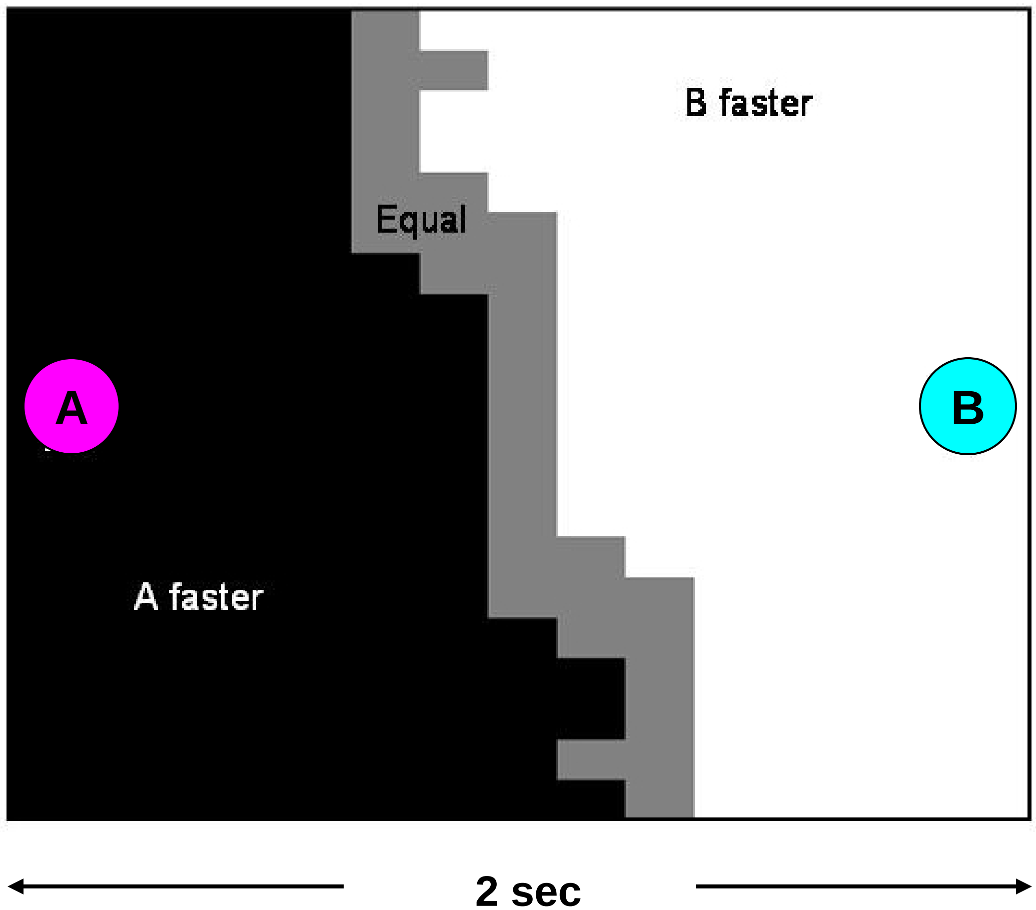
Cost maps generated using the motion capture data reflect actual human capability unlike the simple distance based cost map.

Opponent Modeling: Basketball



Problem: B wants to shoot from the closest position to the basket without being intercepted by A player. How long will it take each player to reach different locations?

Cost Map Analysis



Difference of cost maps identifies areas that B player can reach faster than A player.

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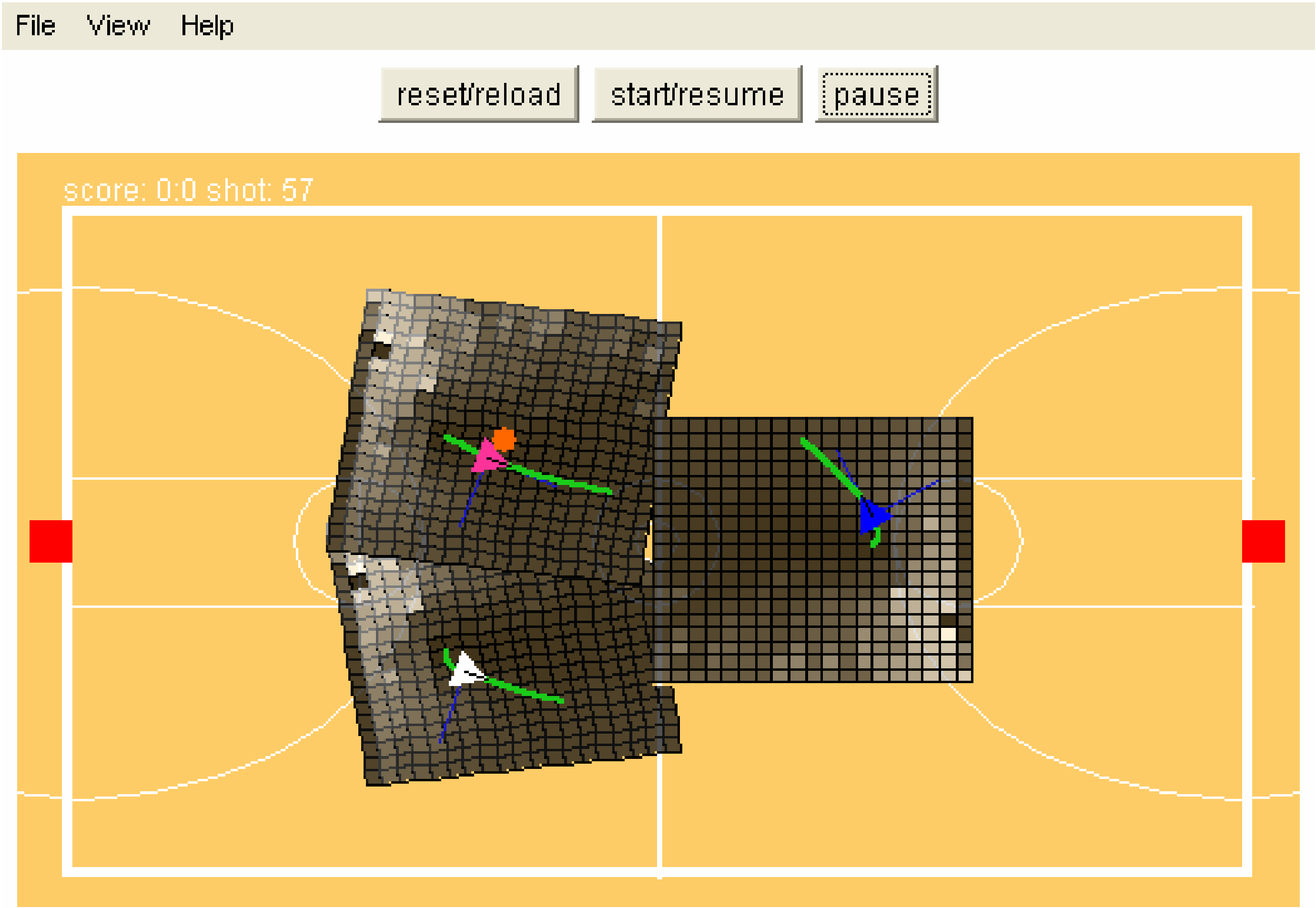
Incorporating PCM into Simulation



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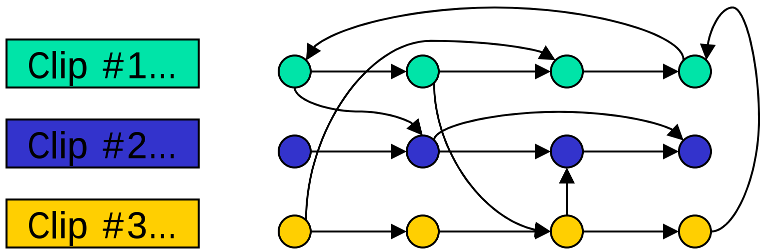
TeamBots basketball simulation: bots are restricted to paths extracted from human motion capture graphs

Creating Physically Variable Agents

Parametric

Exemplar Based

Velocity
Acceleration
Turning Radius



To create physically variable agents, we can edit the motion graph directly since the motion graph is a visual representation of the physical capabilities of our character.

Non-Parametric vs. Parametric Models

- Designer does not have to parameterize the behaviors.
- Requires large data set of exemplars to create motion graphs.
- Designer can edit the motion graph directly to produce a visual model of the agent's capabilities.

- Designer must select suitable parameters.
- Small set of data required to tune parameters.
- No intrinsic visualization, although simulations can be constructed

Contributions

- Introduced a new non-parametric physical capability model of human behavior suitable for use in software agents and virtual training environments
- Potential model applications:
  - Improving agent planning
  - Improving reactive behaviors
  - Opponent modeling
  - Creating physically heterogeneous agents

Future Work

- Validating accuracy of model against human behavior
- Methods of pre-computing cost maps
- Incorporate physical capability model into mixed human-agent teamwork scenarios to improve agent performance

Thanks!

- Moshe Mahler
- CMU Motion Capture Lab personnel
- Mike Lu

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