# Dynamic Maneuvers in a 3D Galloping Quadruped Robot

David E. Orin and Darren P. Krasny
Dept. of Electrical and Computer Engineering
The Ohio State University

# Dynamic Maneuvers

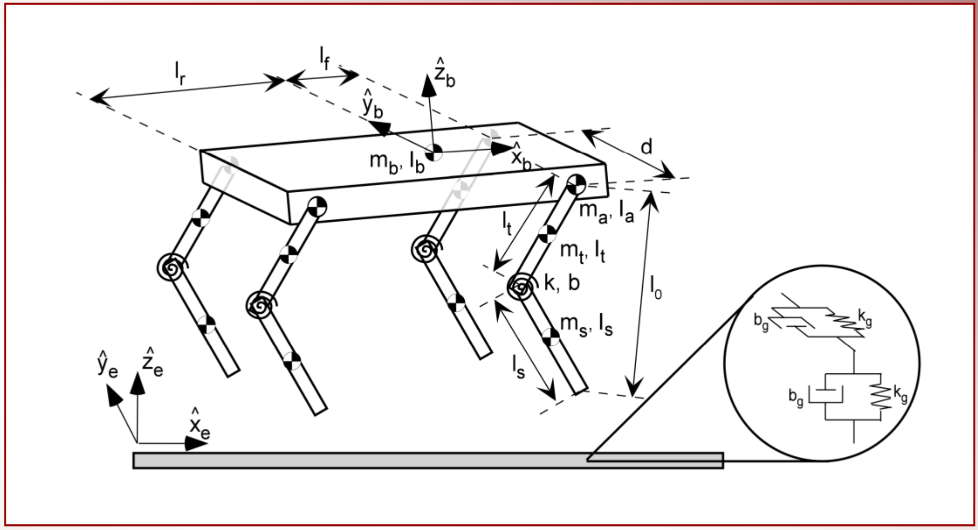
- Sudden changes in trajectory or speed
- Turning, sudden starts/stops, running jumps
- Initiating, terminating, or interrupting *high-speed* dynamic locomotion
- Difficulty: Dynamic stability, hybrid control dynamics, hard to observe in nature

# Objectives

- Find solutions to dynamic maneuvers
  - High-Speed Turn
  - Running Jump
  - → High-speed running gait (Gallop)
- Develop flexible control architecture
- Use multiobjective genetic algorithm (MOGA)

# Dynamic Model

- Articulated legs with 3 DOF, nonzero mass
- Asymmetric body mass
- Passive knee compliance
- Compliant contact model
- Static, kinetic friction

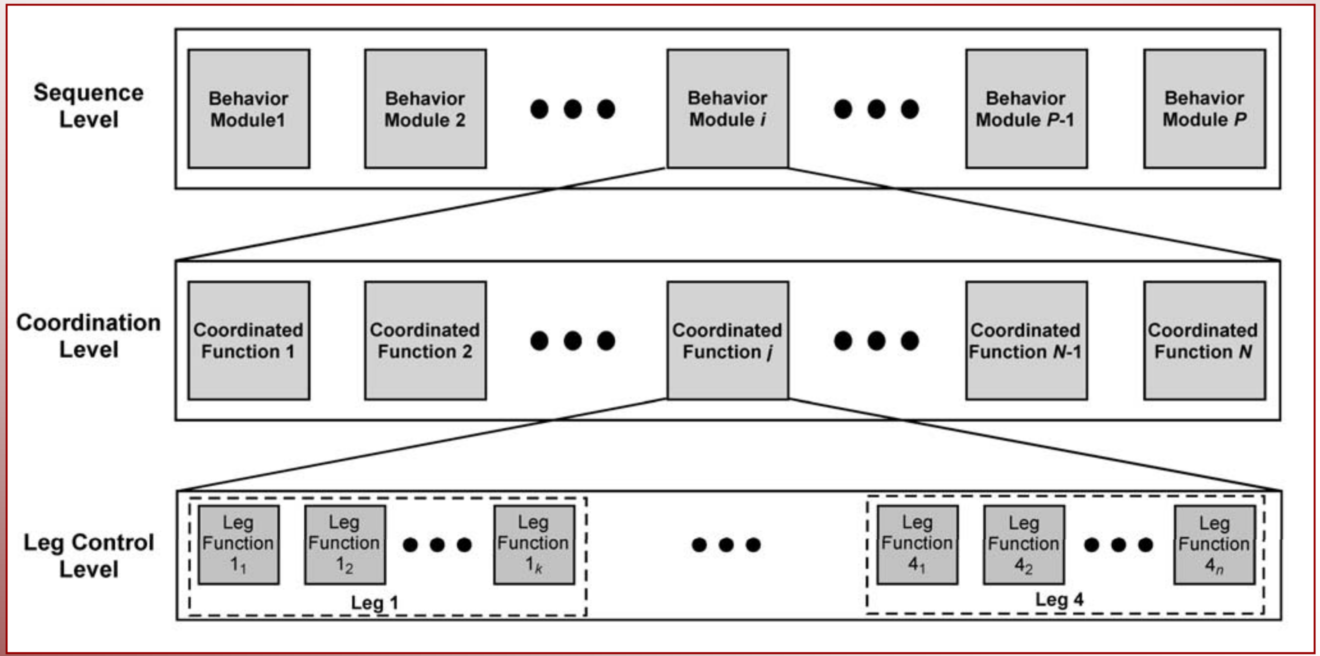


# Dynamic Simulation

- Dynamic simulation used to compute quadruped robot dynamics
- *DynaMechs* package developed by Scott McMillan – used for recursive dynamics computation

# Controller Architecture

- Modular, hierarchical structure
- Flexible: Define cyclic or one-shot behaviors
- Low-level motor primitives defined for each leg
  - Basic movements for running or maneuvering
  - Minimal parameters vs. maximum functionality



# Leg Primitive Functions

| **Function** | **Description** |
|---|---|
| FREE | Allow all joints to move freely. |
| TRANSFER | Transfer all joints from initial to desired ending positions over period *T* using a cubic spline. |
| EARLY-RETRACTION | Rotate hip rearwards at desired tangential velocity. |
| STANCE-CONTROL | Maintain desired tangential velocity of foot; maintain touchdown ab/ad angle; achieve desired knee energy at max compression. |

# The Genetic Algorithm

- Genetic algorithm (GA) overview
  - Direct random search of unknown parameter space
  - Parameters encoded in a *chromosome*
  - Chromosome is altered via genetic operators
  - Algorithm similar to Darwinian evolution
    - Each chromosome considered an individual
    - Group of all individuals considered a population
    - Population changes over several generations via genetic operators
    - Individuals ranked according to their *fitness* with the best performers able to reproduce

# Genetic Operators

- ***Selection***: Fittest individuals get to reproduce
  - Elitism used to preserve the best individual(s)
  - Fitness-proportionate (Roulette-wheel) selection
    - Higher fitness → better selection probability
  - Multiple copies of fittest individuals in mating pool

# Genetic Operators (cont'd)

- ***Crossover***: Individual *genes* are swapped between two parents to form two new children
- ***Mutation***: Genes of each individual are randomly changed with a probability $p_m$

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# GA Summary

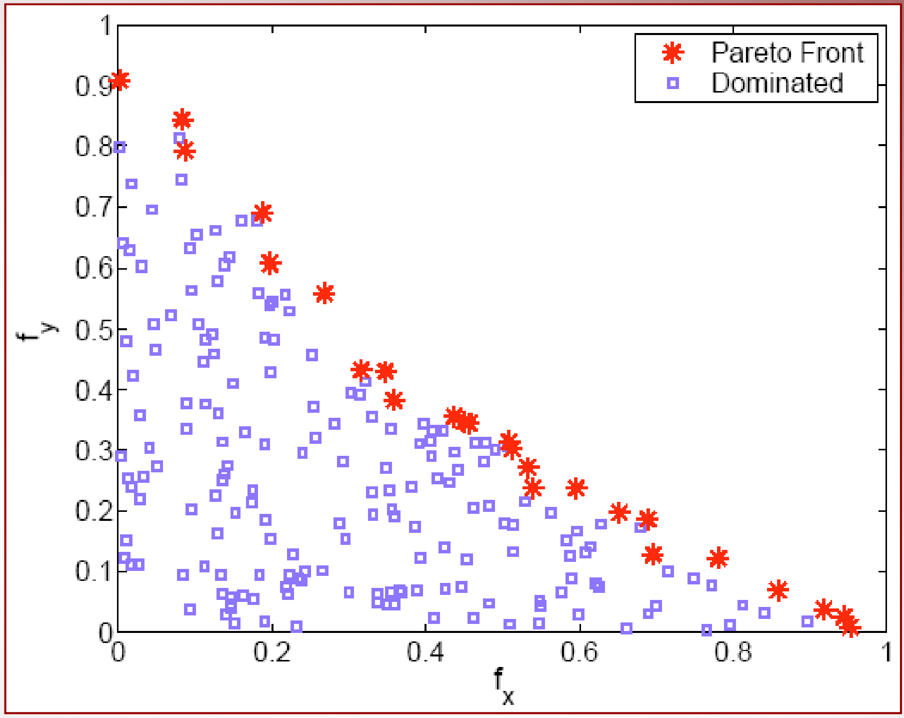
**For Generation = *1* to *N*** $N$ = 250 max

1. Evaluate fitness of all $S$ individuals in the population $S = 32$
2. Select fittest individuals for mating pool
3. Crossover individuals in mating pool with probability $p_c$ (60%)
4. Mutate each individual's genes with probability $p_m$ (5%)

# Multiobjective Genetic Algorithm

- Trade-offs among multiple criteria
- Vector-valued fitness

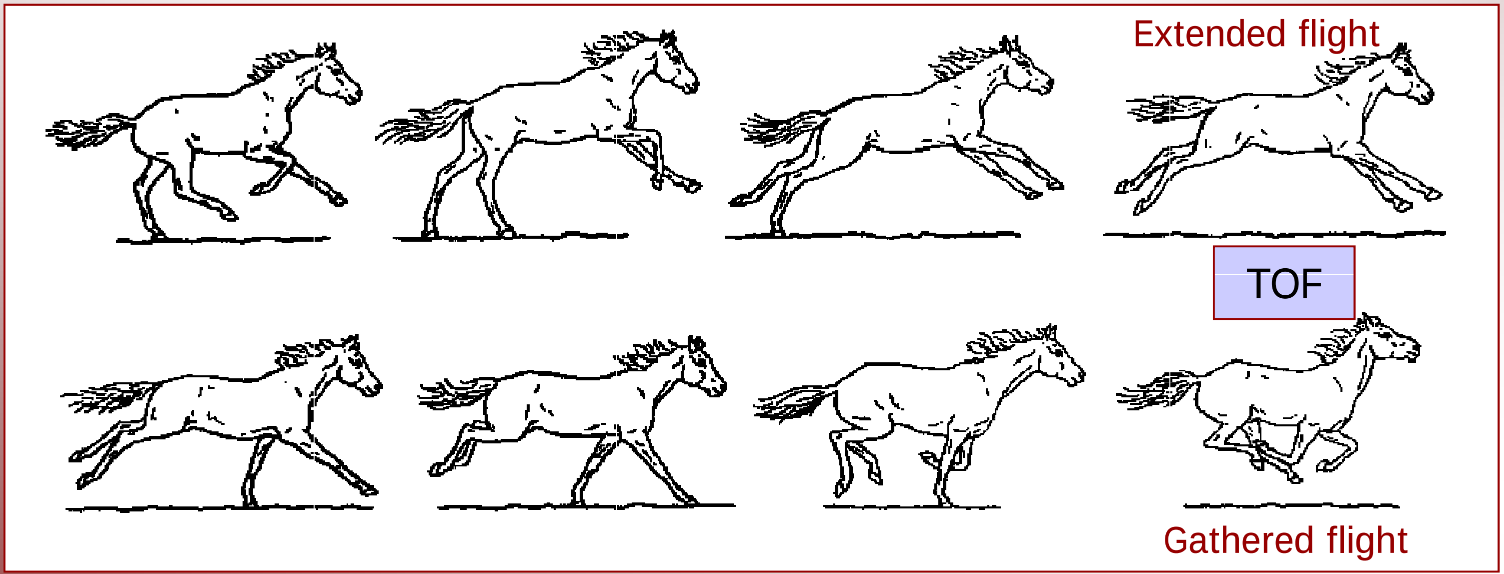
  $f=[f_1, f_2, \ldots, f_n]^T$
- Pareto front: set of *non-dominated* solutions
  - **Domination**: One solution ≥ the other in each position, > in at least one position




Example of a Pareto Front.

# The Gallop

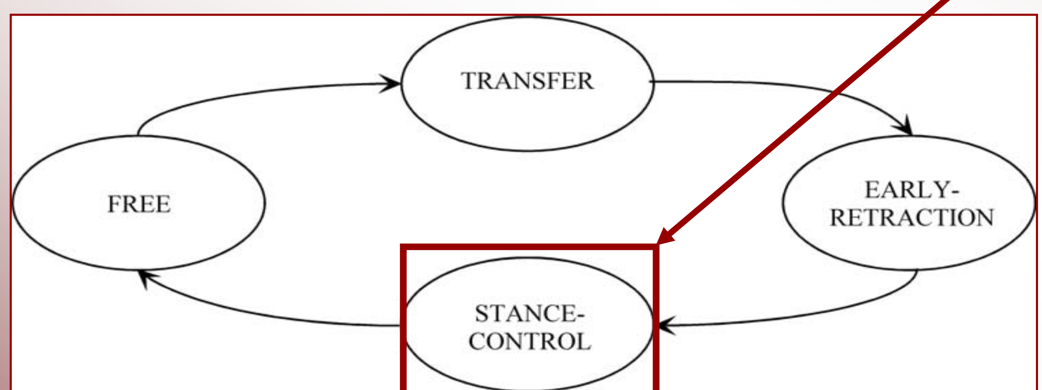
- Preferred gait for high-speed quadrupedal locomotion
- Asymmetric footfalls (e.g., LR-RR-LF-RF)
- At least one flight phase (gathered)
- Early retraction of limbs
- Smoother than trot, bound



# The Turn

- State machine approach
- Control parameters (12)
  - Four touchdown ab/ad angles
  - Four stance-phase hip velocity target values
  - Four stance-phase knee energy target values
- Evolve a single stride at a time
  - Multiple turning angles

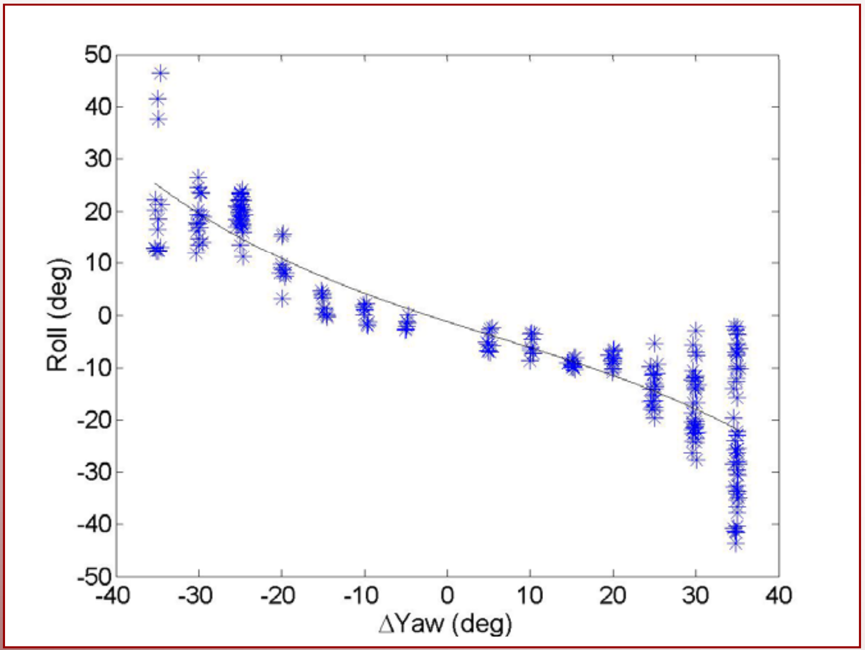
Stance phase



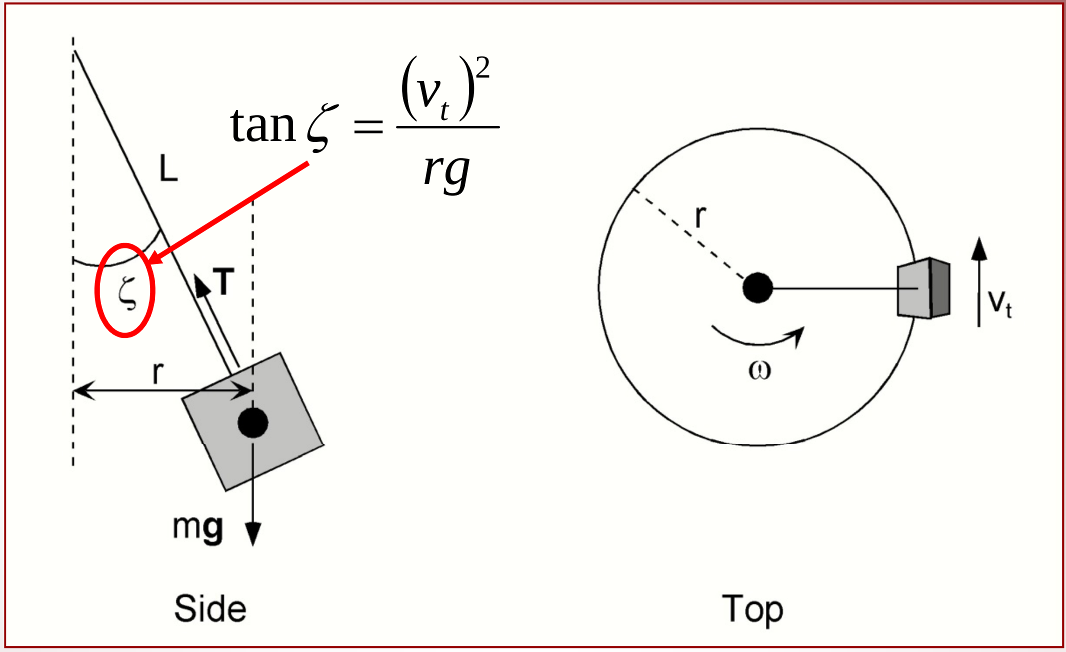
# The Turn Fitness Function

- Fitness function: $f = \left[ f_a, f_{\Delta\alpha}, f_c \right]^T$
  - General accuracy
    - Body state variables other than yaw, yaw rate
    - Acceptable ranges for roll, roll rate
  - Turn angle accuracy
    - Achieve the desired change in yaw angle
  - Correctness
    - Correct number of footfalls, correct footfall sequence, no excessive leg spread

# Turn Results

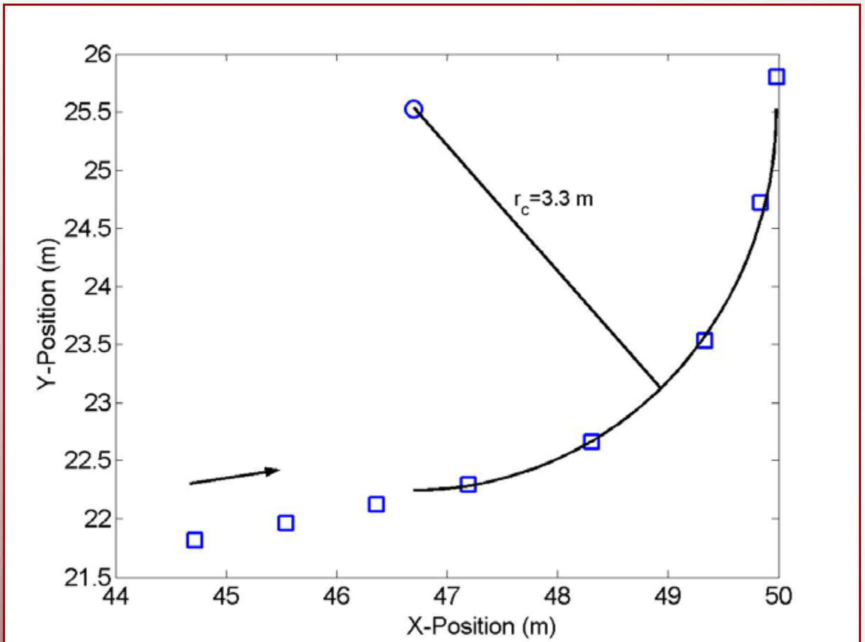



Roll vs. change in yaw for the turn.

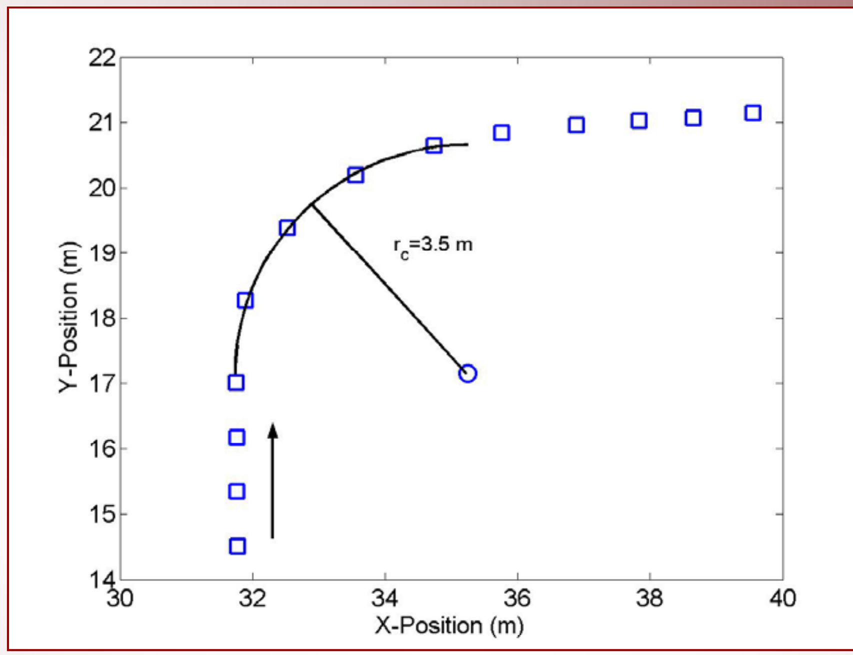



Conical pendulum model for the turn.

# Multiple-Stride Turning




Multi-stride turn in the CCW direction.

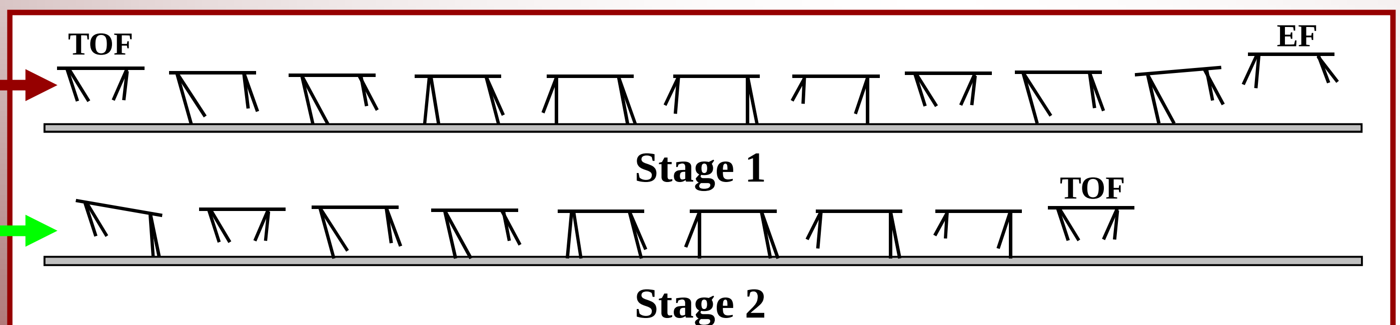



Multi-stride turn in the CW direction.

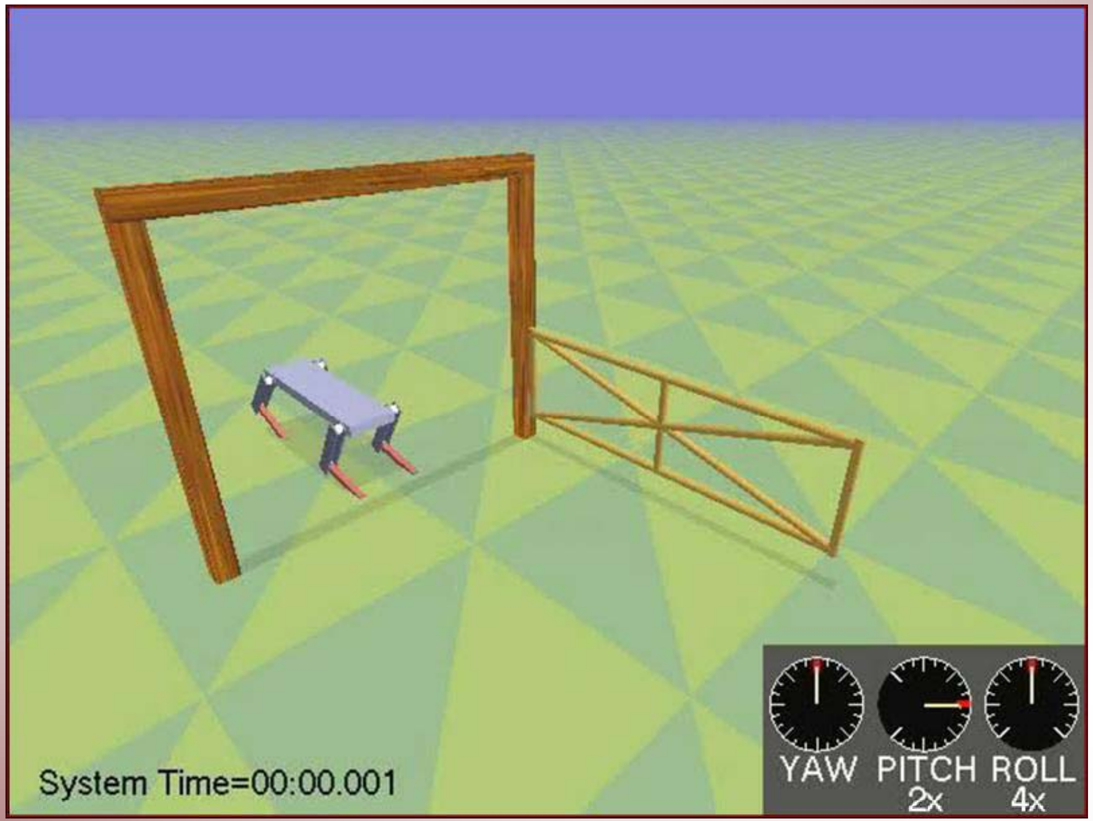
# The Running Jump

- Same state machine as the turn
- Control parameters (17):

  hip angles, velocity biases, knee energy
- Evolved in stages
  - Stage 1: Jump
  - Stage 2: Landing



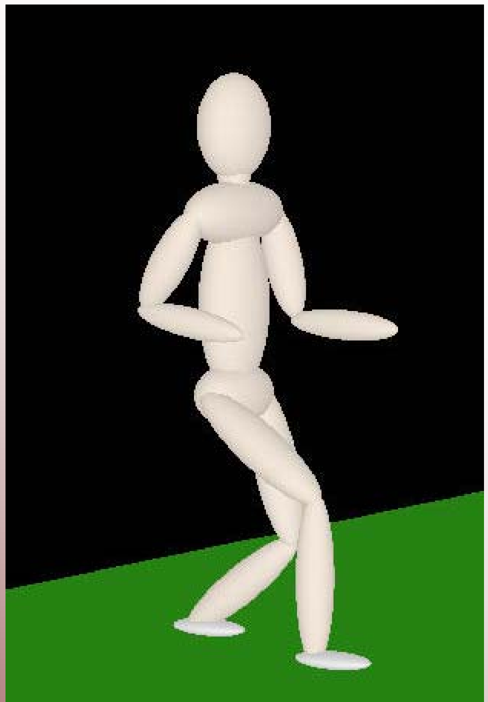
# Results



# Summary

- Non-traditional solution approach for complex motions, bio-inspired system
  - Evolutionary optimization vs. traditional approaches
    - No simplifying assumptions required
    - Emergent, unanticipated solutions
- Future of robotics
  - Realization of biological abilities
  - Non-traditional, biologically-inspired solution approaches

# Future Work



- Develop dynamic movements for biped
- 26 degree-of-freedom model (DOF) in *RobotBuilder*
  - 6 DOF legs
  - 4 DOF arms
  - 6 DOF torso