10. Complex Hardware Morphologies: Walking Machines

Contents

1. Introduction

- Traditional geometric approach
  - Based on modeling of the robot and derivation of leg trajectories
  - Computationally expensive and requires fine tuning of parameters
  - Recently employed genetic algorithms for optimization

- Behavior based approach
  - Trajectories emerge from the coordination of several control modules
    - Complexity of legged robot can be reduced if one takes into account the symmetries of the body
  - Local computation is inspired upon biological mechanisms

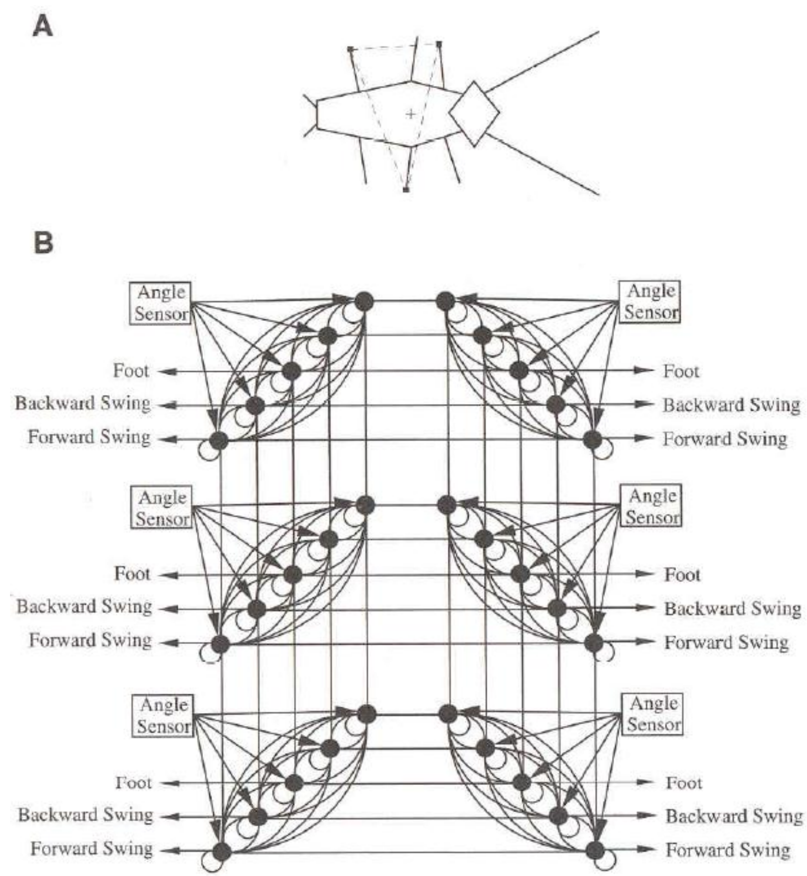
2. Evolving Simulated Insects

- Beer & Gallagher (1992)
  - Artificial evolution can find robust locomotion controllers without priori knowledge

- Evolution of walking for simulated hexapod insects
  - Insects can move only if it is statically stable. (stance/swing)
  - Displacement of body is computed under dynamics by summing the forces exerted by all stancing legs.
  - Each leg has a sensor that measures the angle between the leg and the body of the robot
  - 5 neurons: 3 neurons (up/down, forward swing, backward swing) and 2 hidden units
  - Inspired upon the neural circuitery, which is used by cockroaches for locomotion

2. Evolving Simulated Insects

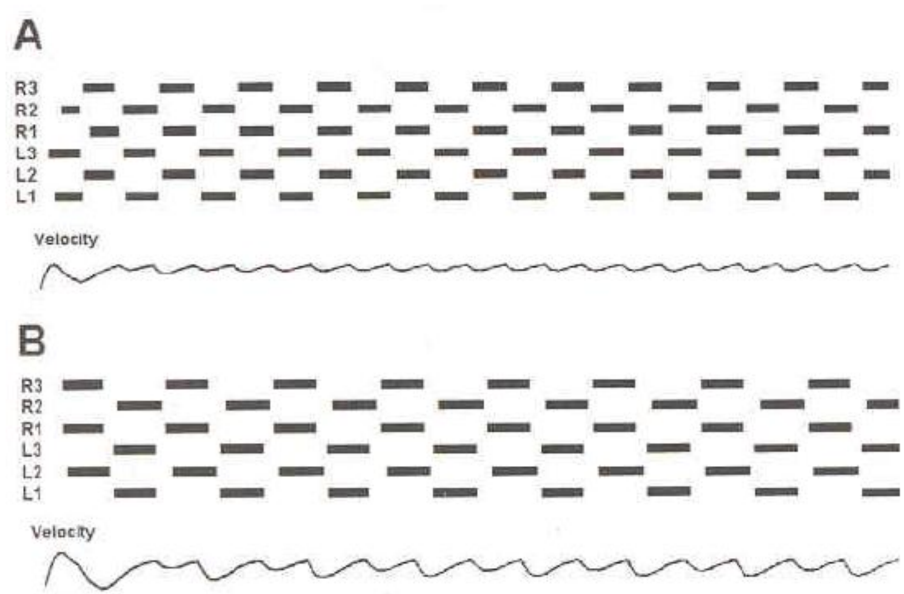
- Used simple genetic algorithm
- Fitness function (behavioral fitness)
  - The forward distance traveled within the allocated time is normalized by the total distance if moved at maximum speed
- Two different trail and averaged its fitness
  - Receiving the angle sensor info
  - Not receiving sensor info
- To evolve robust controllers in absence of external inputs



2. Evolving Simulated Insects

- Discovered a pattern of leg movement as tripod gait
  - Type of gait used by all fast moving insects

- Evolved controller displayed higher stepping frequency and more regular phasing in the sensory system, but capable of moving forward even in its absence



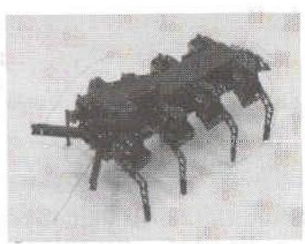
3. Evolution of Walking Machines

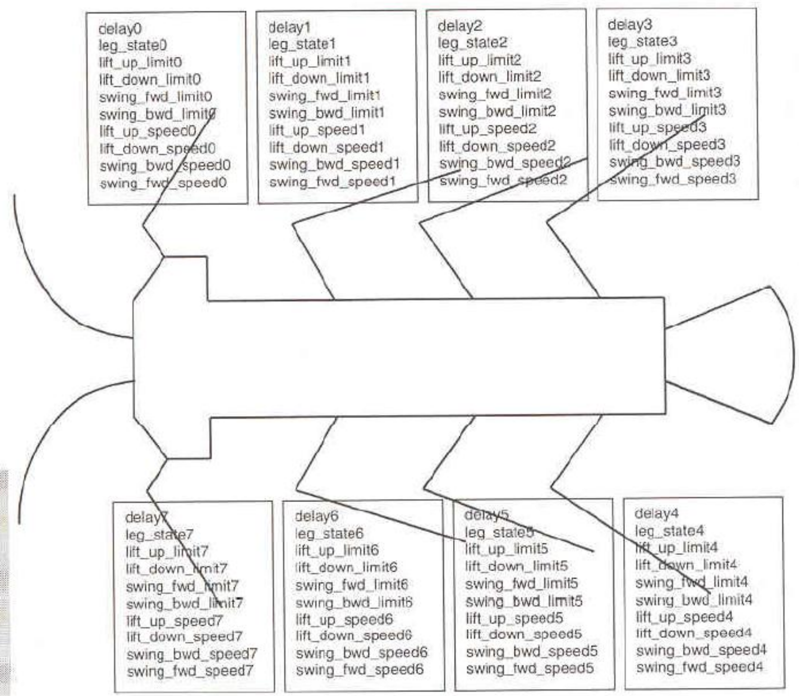
- Lewis et al. (1992)
  - First attempt to evolve a physical walking machine
  - An hexapod robot with two DOF for each leg (lift and swing)
  - Evolve using a neural network and did not use sensors for locomotion
  - The resulting behavior is scored by a combination of objective measures and visual inspection, and the score is fed back to the genetic algorithm as fitness

- Combinations of weight and threshold parameters, the two neurons began to oscillate at a particular frequency and phase.
  - Coupled oscillator, a phase difference of 90˚ , produced a stepping motion

3.1 Online Evolution

- Gomi and Ide (1998)
  - Evolved walking patterns for an octopod robot
  - Each leg is characterized by 8 parameters describing its motions
  - Motor current sensors and two belly contact sensors are used for the evaluation of the fitness function





3.2 From Simulation to Physical Robots

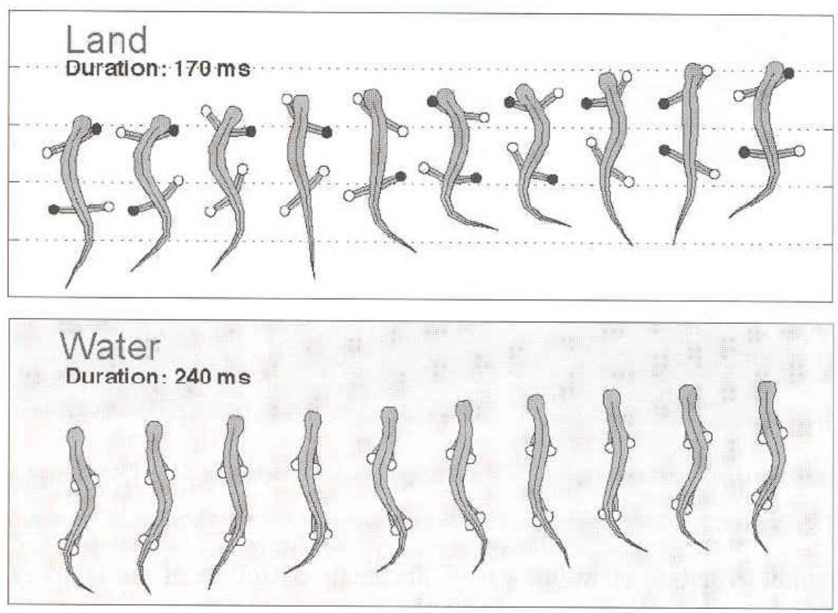
- Jakobi (1998)
  - On the octopod robot, infrared and bumper sensors are provided
  - Avoiding objects with its infrared sensors and backing away from objects that hit with its bumper
  - Fitness function is incremented by the resulting value δ
    1. No objects within sensor range, δ is the sum of the left and right side speeds
    2. Objects on right side, δ is the right side speed minus the left side speed
    3. Objects on left side, δ is the left side speed minus the right side speed
    4. Hit an obstacle, δ is minus the sum of the left and right side speeds
  - Fit controllers is evolved within around 3500 generations

4. From Swimming to Walking

- Lewis (1996)
  - Evolved swimming controllers for a simulated lamprey incrementally evolved walking controllers for a quadruped robot with a flexible spine
- Ijspeert (1998)
  - Controller consisted of a *central pattern generator* (CPG), capable of producing oscillatory patterns with no external inputs
  - These oscillations are used for rhythmic muscle contraction in both swimming and locomotion

4. From Swimming to Walking

- Evolving swimming controller
  1. Individual oscillator is evolved using a fitness function that rewarded the production of regular oscillations
  2. Evolved the coordination of several copies of previously evolved segmental oscillators
  3. Incrementally evolved to compensate for varying water currents

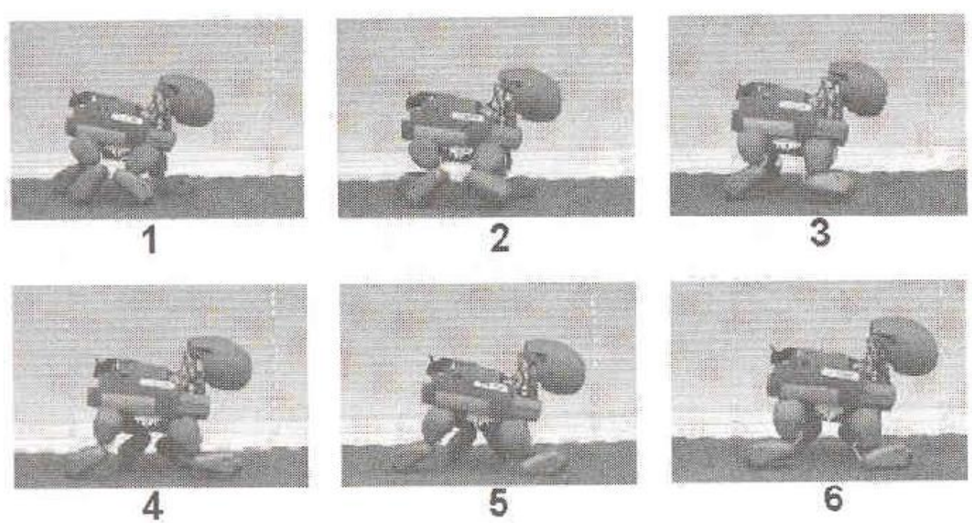


4. From Swimming to Walking

- The goal is to evolve controllers than can switch between walking and swimming
  - Chromosome consisted of 39 real valued numbers
  - A simple genetic algorithm is employed to evolve a population of 40 individuals
  - Evaluated by an objective fitness function that rewards;
    1. Fast walking on a straight line
    2. A large range of speeds depending on the amount of excitation
    3. Usage of all four limbs
  - After 40 generations, all runs converged to controllers capable of producing a gait.
  - Salamander is capable of swimming, but its speed is 35% lower than the lamprey due to extra inertial forces produced by the limbs

5. Dynamic Gait for a Quadruped Robot

- Hornby et al. researcher at Sony Corporation (1999)
  - The goal is to evolve controllers capable of moving in a straight line as fast as possible without using sensory information
  - Steady state genetic algorithm with tournament selection is run on the CPU
  - Fitness function is computed using only info available through onboard sensors



6. Conclusions

- The variety of simulated and physical robots are similar in the following four aspects:
  - Stage evolution – there is no distinction of evolutionary phases
  - Sensor-less walk – sensors are evaluate the fitness of the individual, but is not passed to the evolutionary control system
  - Coupled oscillator – can rapidly synchronize and well suited for generating regular rhythmic patterns required by walk
  - Static walk – robots with six or more legs are intrinsically static

- Improvement of hardware solution will provide increased flexibility, dynamics and ultimate benefits from a model free evolutionary approach