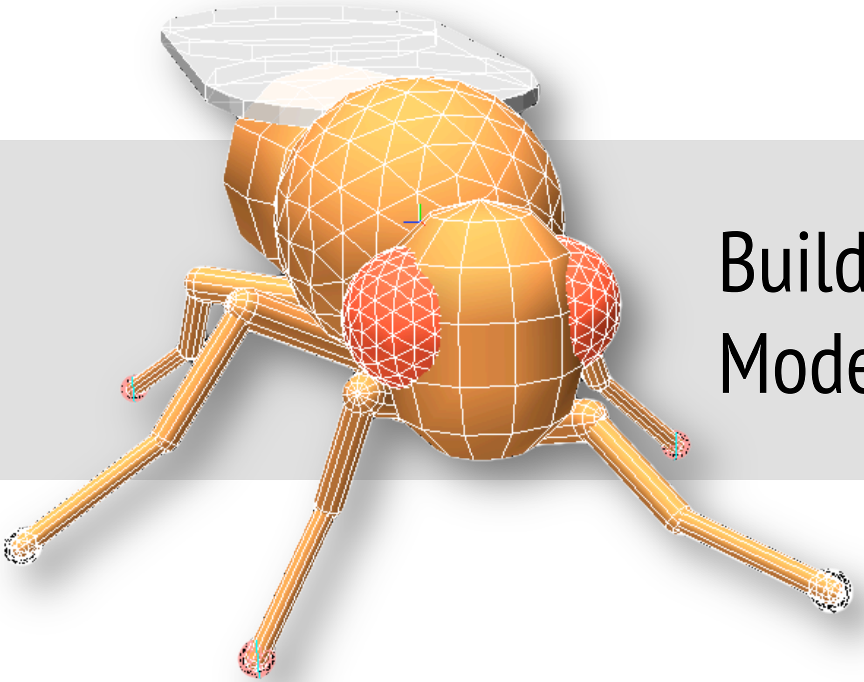


Building a Computational Fly: Modeling *Drosophila melanogaster*

Semester Project: Final Presentation

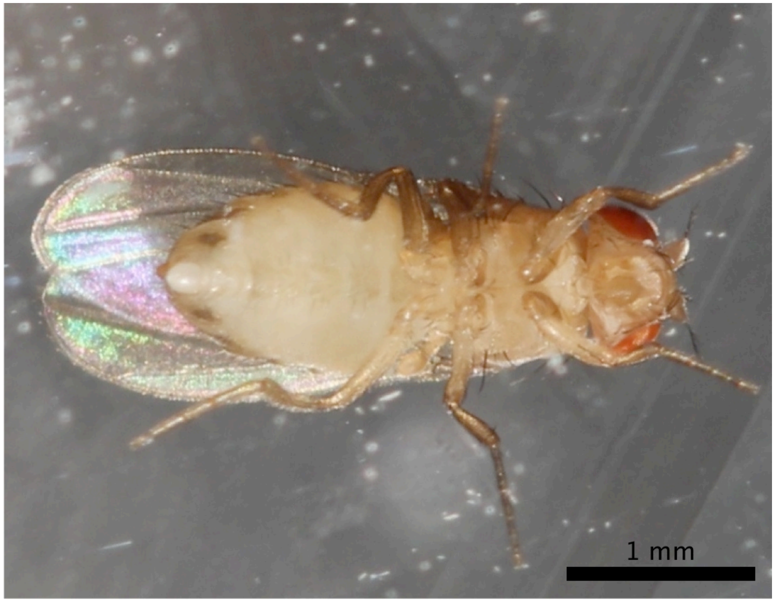
Raphael Cherney

LIS

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

DROSOPHILA

- Commonly known as the "fruit fly"
- Model organism in biological research (extensively studied)
  - Small
  - Short generation time
  - Easy to care for
  - Large brood numbers

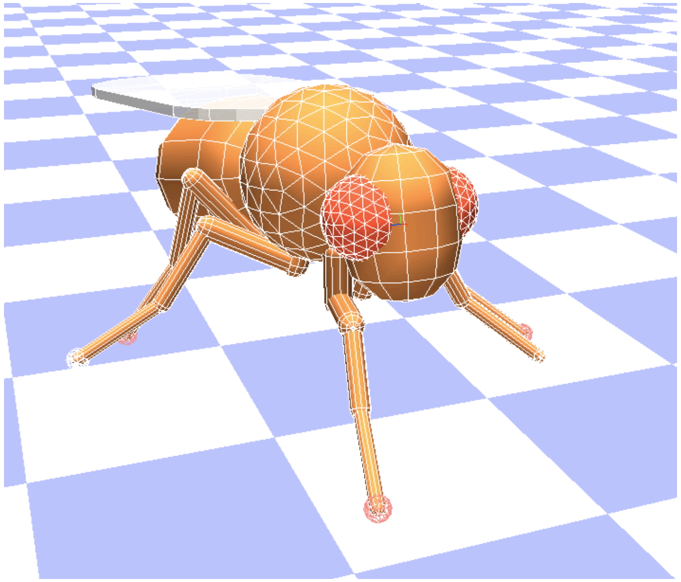


PROBLEM

- *Drosophila* have been extensively studied, but only limited work has been done to understand their locomotion
- By understanding insect locomotion, we can harness insight from millions of years of insect evolution to build more robust, bio-inspired robots
- These same engineering experiments can also help answer biological questions

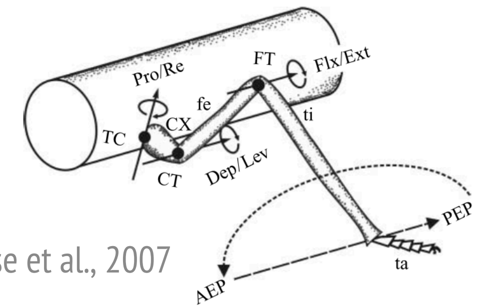
GOALS

- Investigate *Drosophila* morphology and locomotion
- Build a biologically-accurate 3-dimentional model of *Drosophila melanogaster*
- Design controllers to test biological and robotic locomotion questions



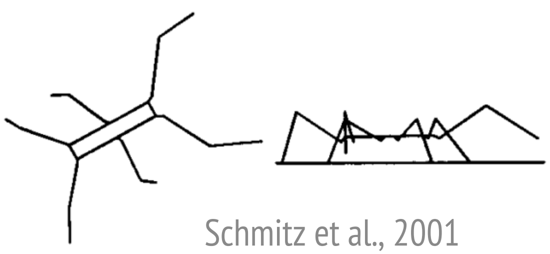
STATE OF THE ART

Stick insects

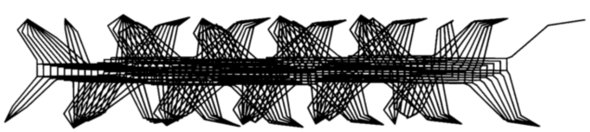


Cruse et al., 2007

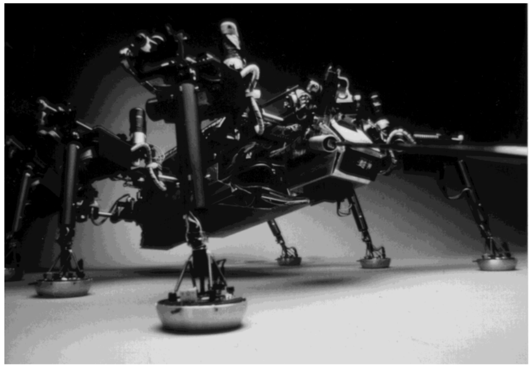
Ekeberg et al., 2004



Schmitz et al., 2001



Cruse et al., 1998



Ferrell, 1993

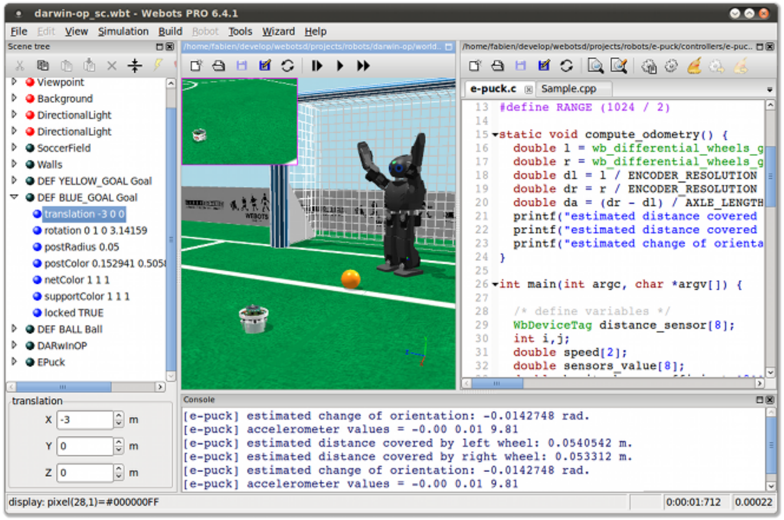
Fruit flies

?

WEBOTS

LIS

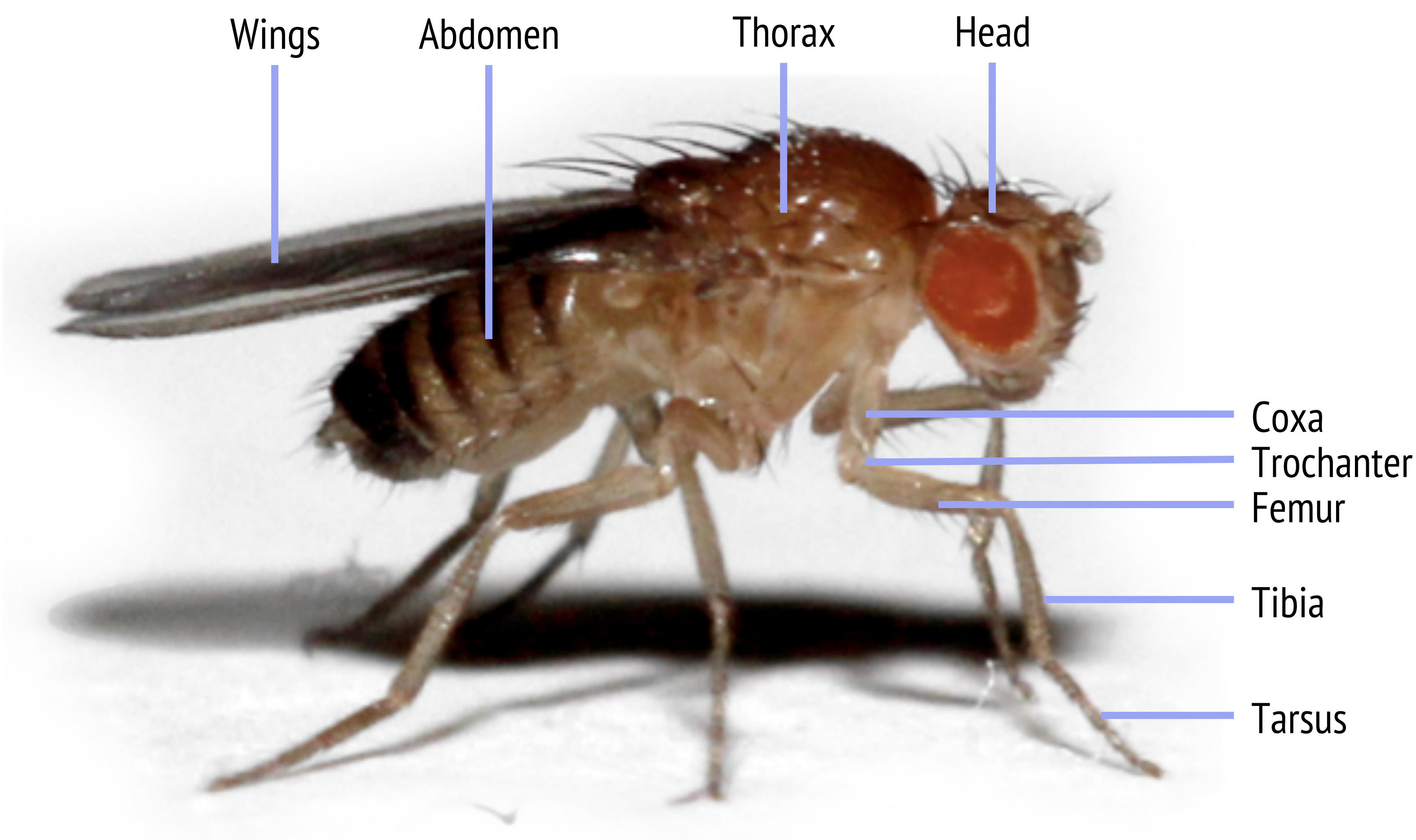
- We are using the Webots™ environment to build and test our model
  - Open Dynamics Engine (ODE) for physics simulation
  - 3D visualization
  - Sensor and actuator libraries to ease implementation
  - Choice of programming languages (C, C++, Java, Python, MATLAB)
  - EPFL knowledge base (BIOROB)
  - Availability through EPFL license
  - Expandable
  - Existing documentation
  - Easier conversion into hardware



Webots™ 6

fast prototyping and simulation of mobile robots

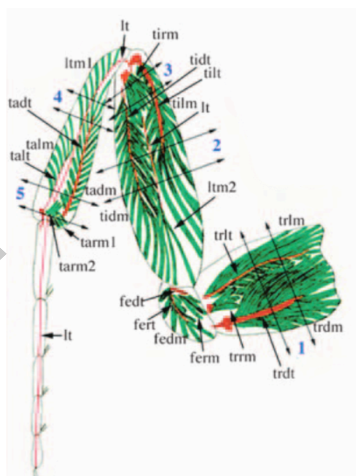
ANATOMY


Wings
Abdomen
Thorax
Head
Coxa
Trochanter
Femur
Tibia
Tarsus

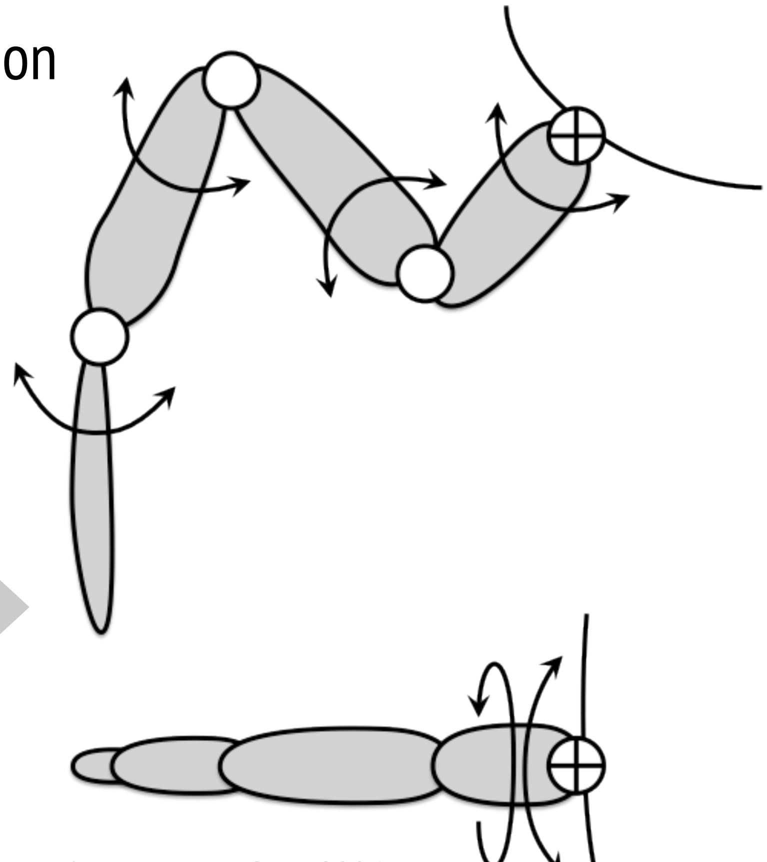
LEG MODEL

- Model based on anatomy and observation
- Each leg has 6 degrees of freedom
  - 6 DoF x 6 legs = 36 total DoF

Soler et al., 2004

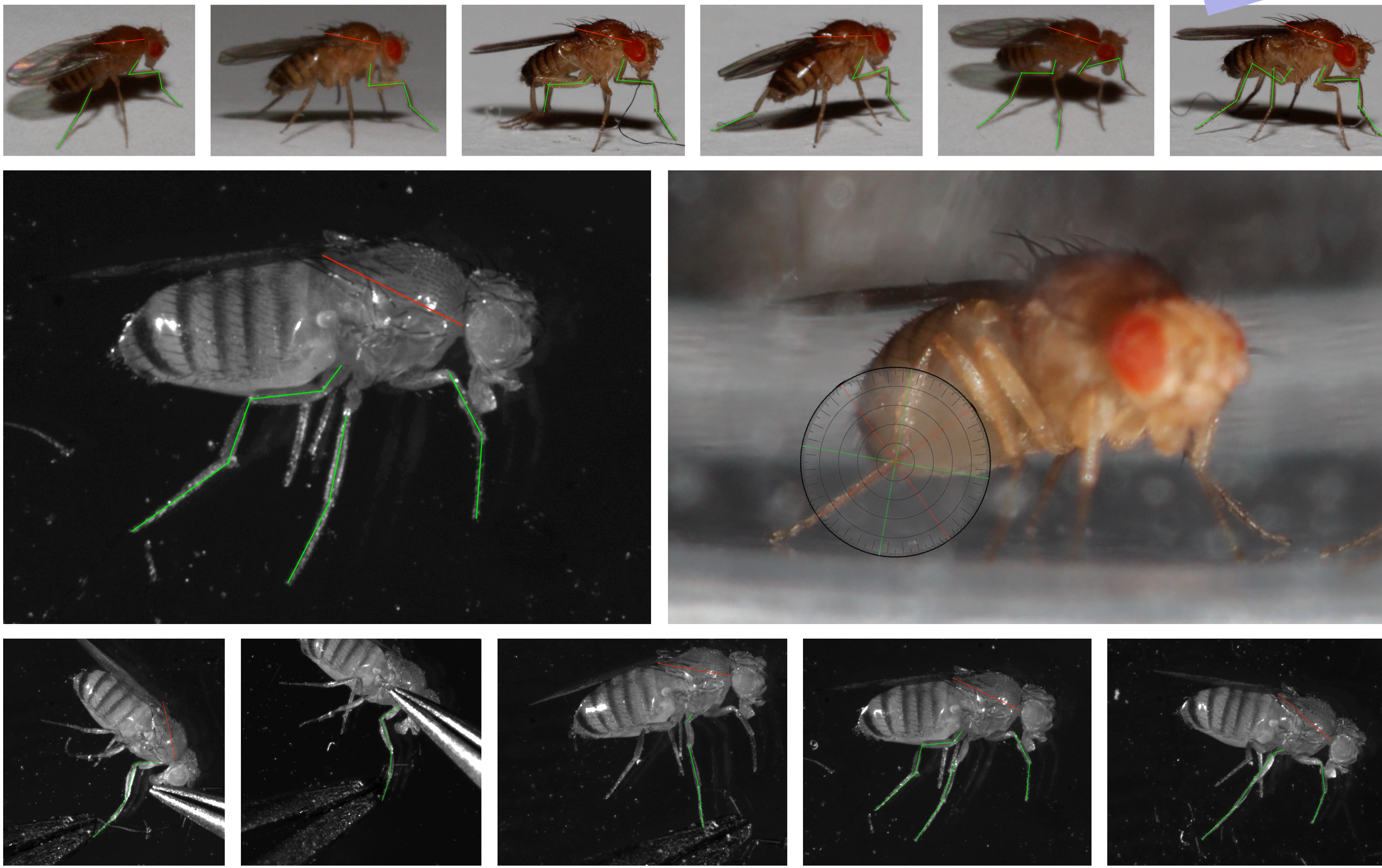


Soler et al., 2004



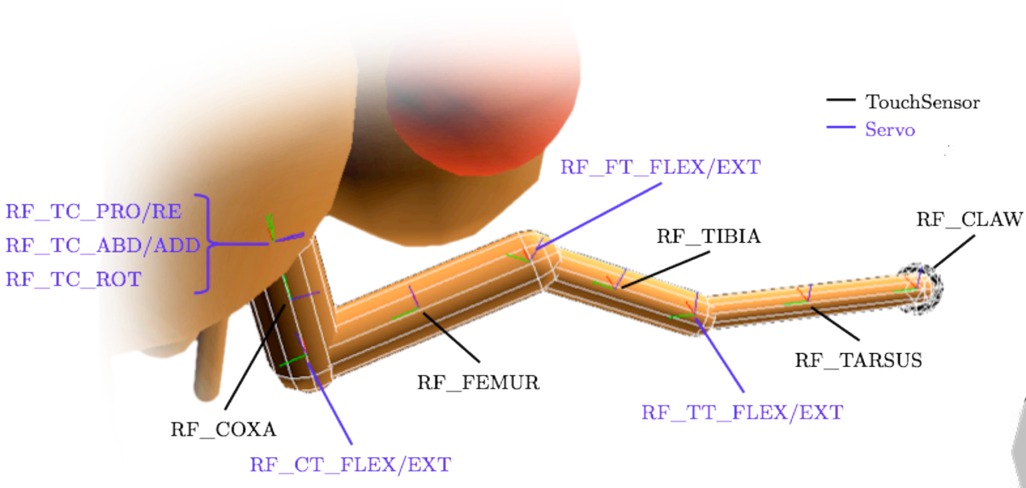
Adapted from Sink, 2006

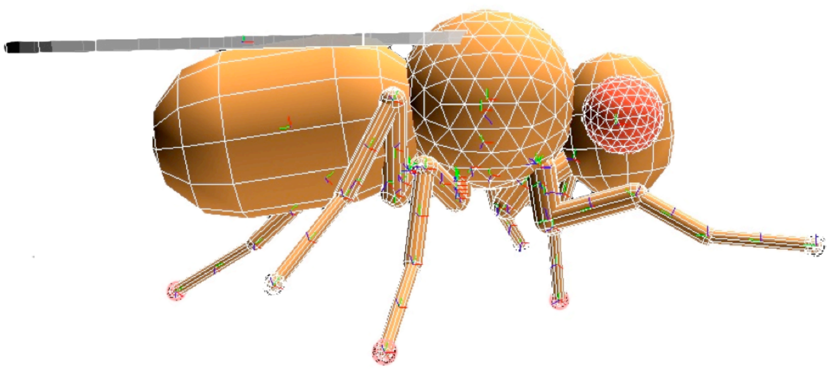
IMAGE ANALYSIS

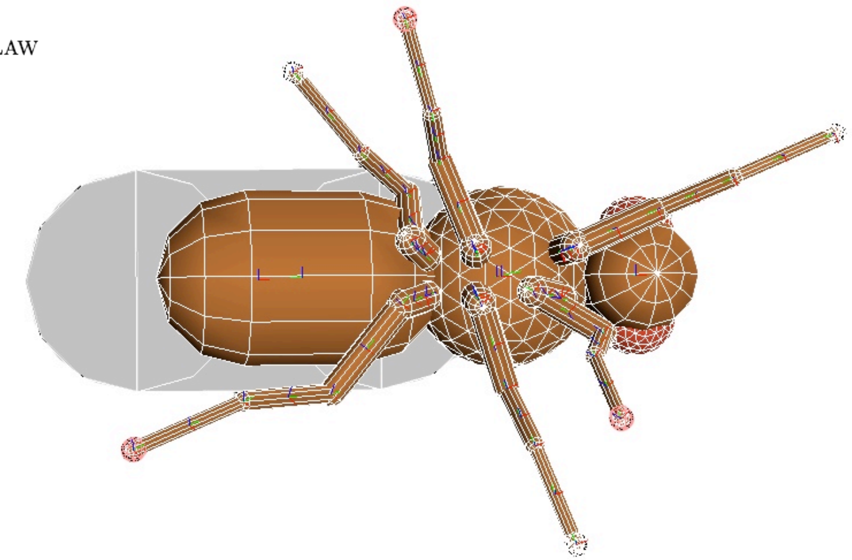


MODEL

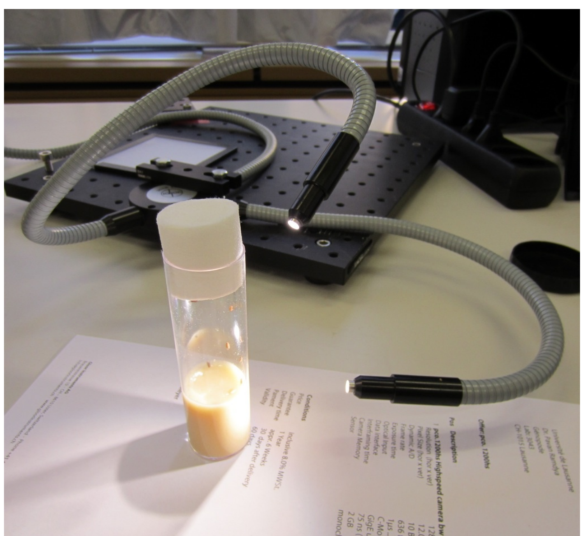
- Biologically plausible fly
- Same morphology as *Drosophila*

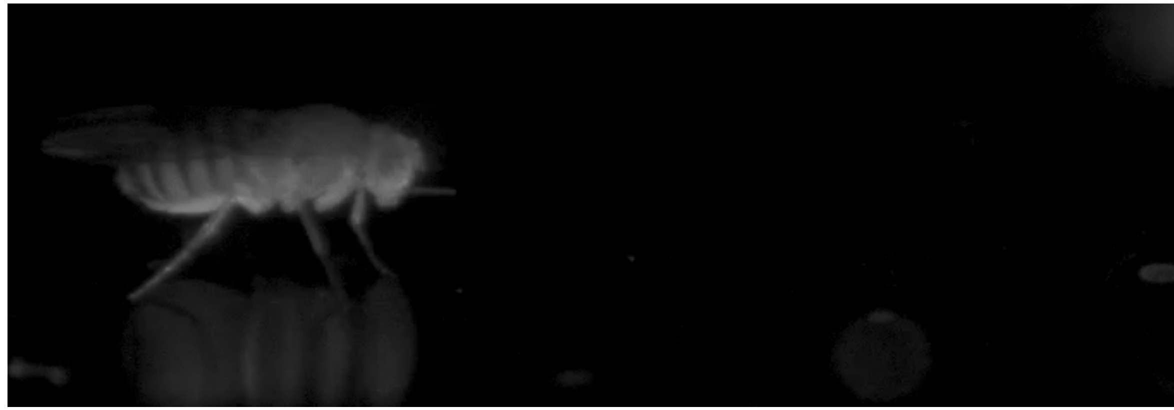


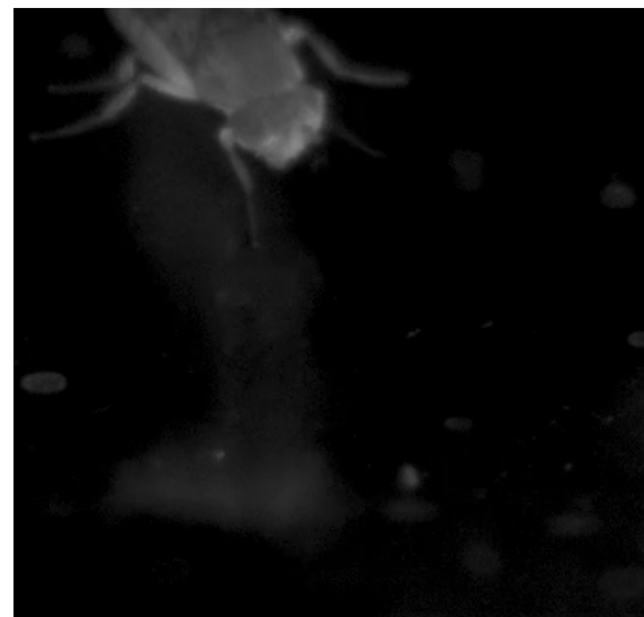




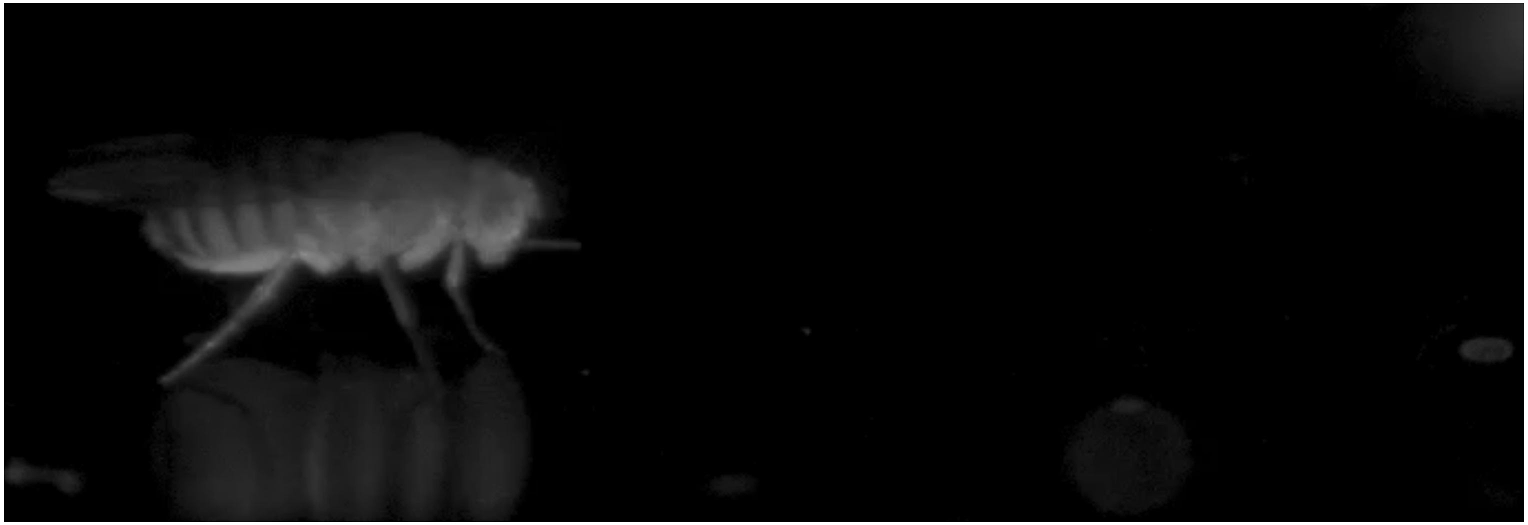
HIGH SPEED VIDEO





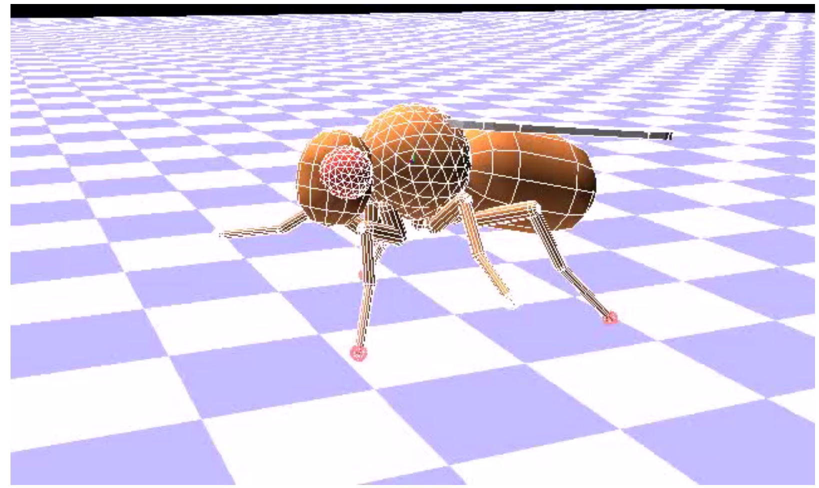


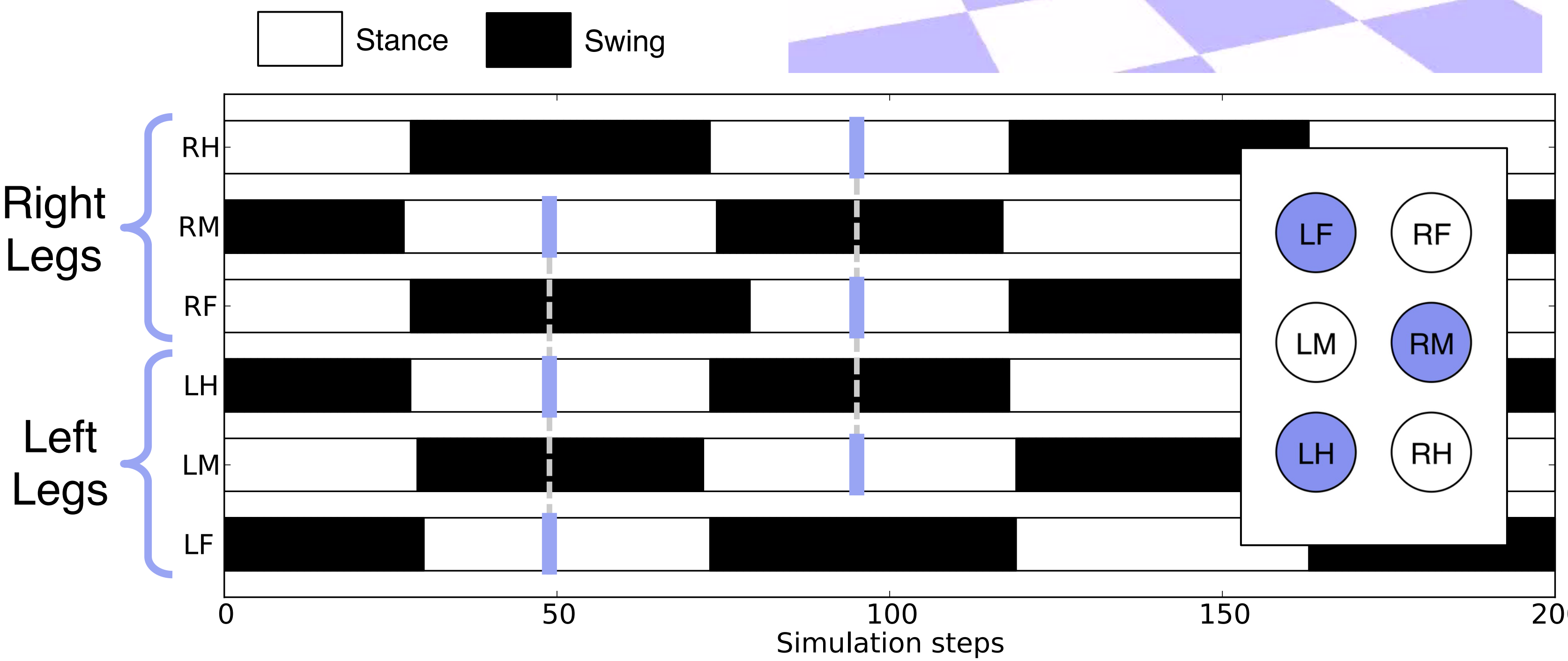
HAND-TUNED CONTROLLER



HAND-TUNED CONTROLLER

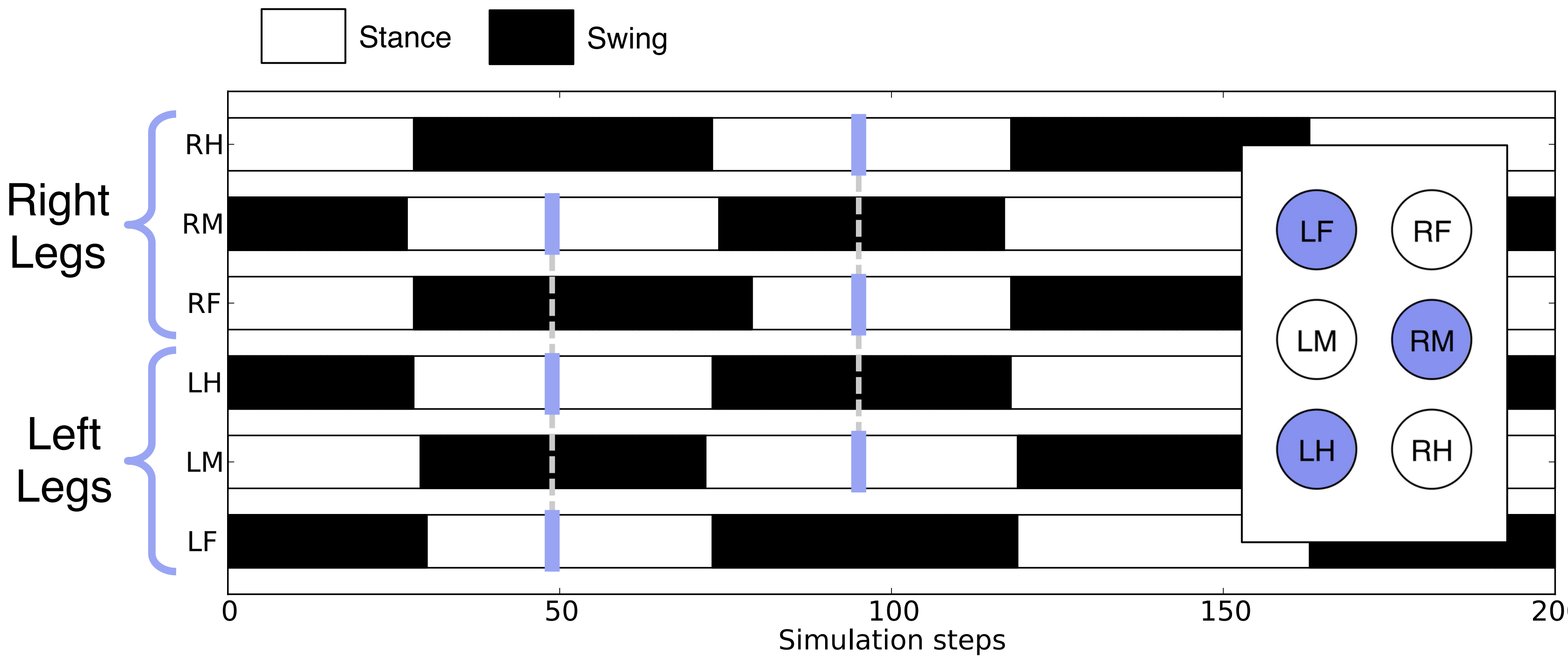
- Alternating tripod gait
  - Statically stable





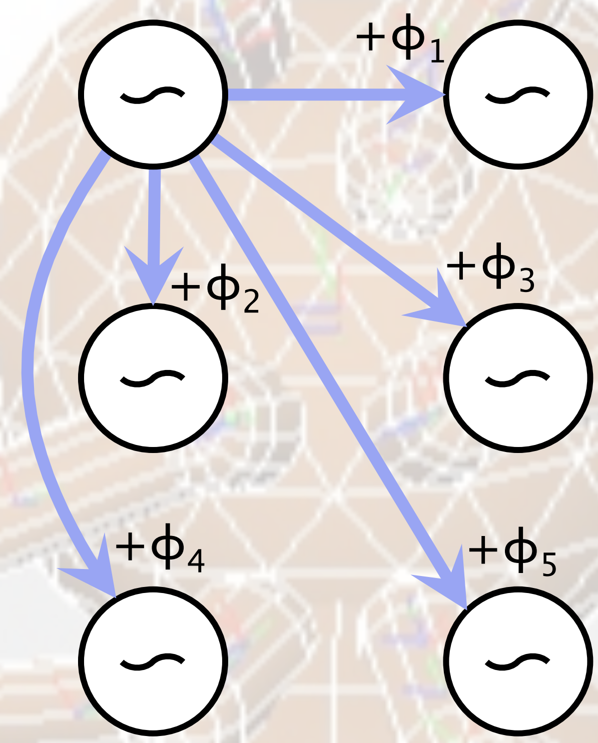
QUESTION

- How well optimized is the biological controller for speed?



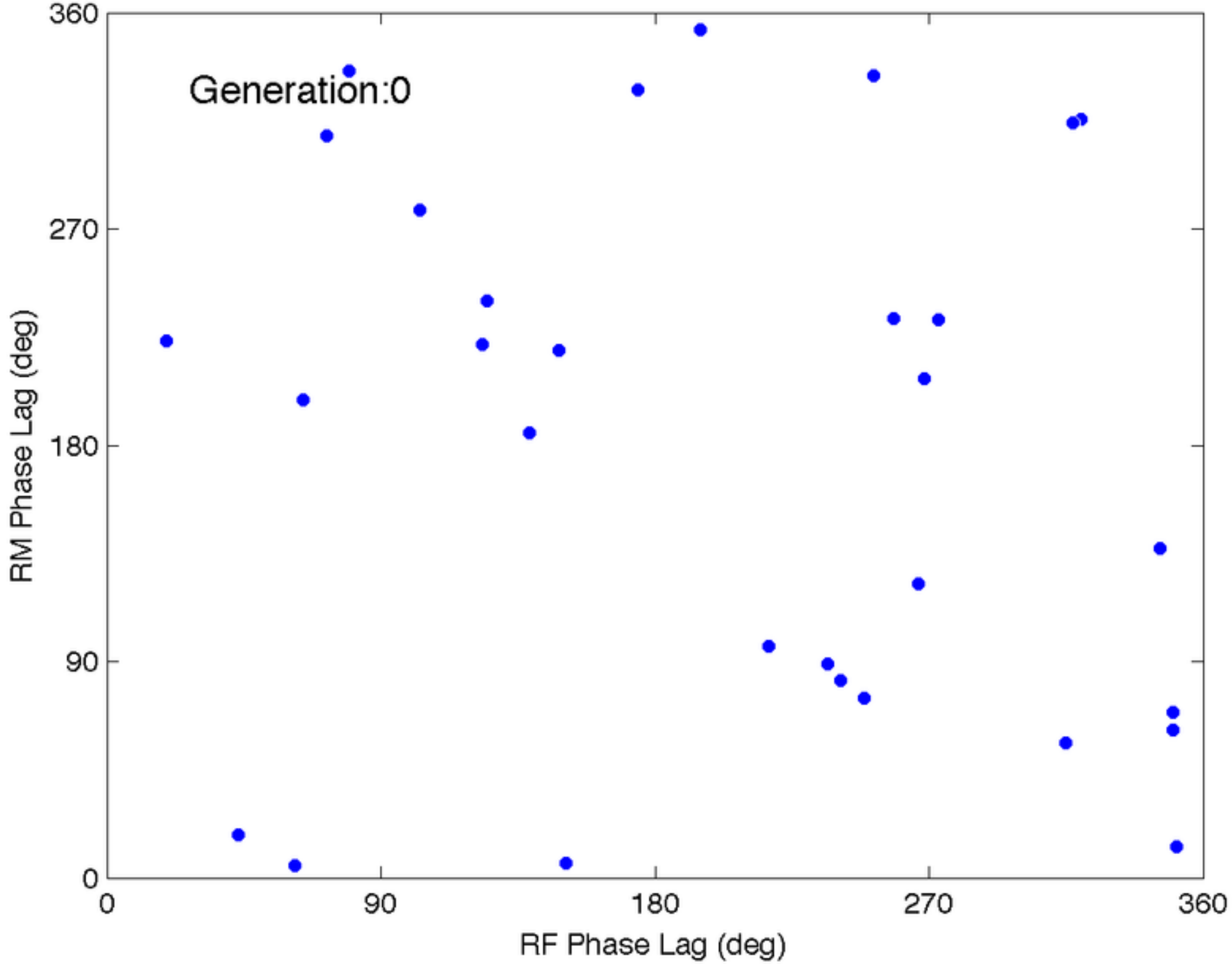
OPTIMIZATION

- Six independent leg oscillators
  - Hand-tuned internal parameters
- Particle Swarm Optimization (PSO)
  - 5-dimensional search space (relative phase lag)
  - Fitness: average speed over run



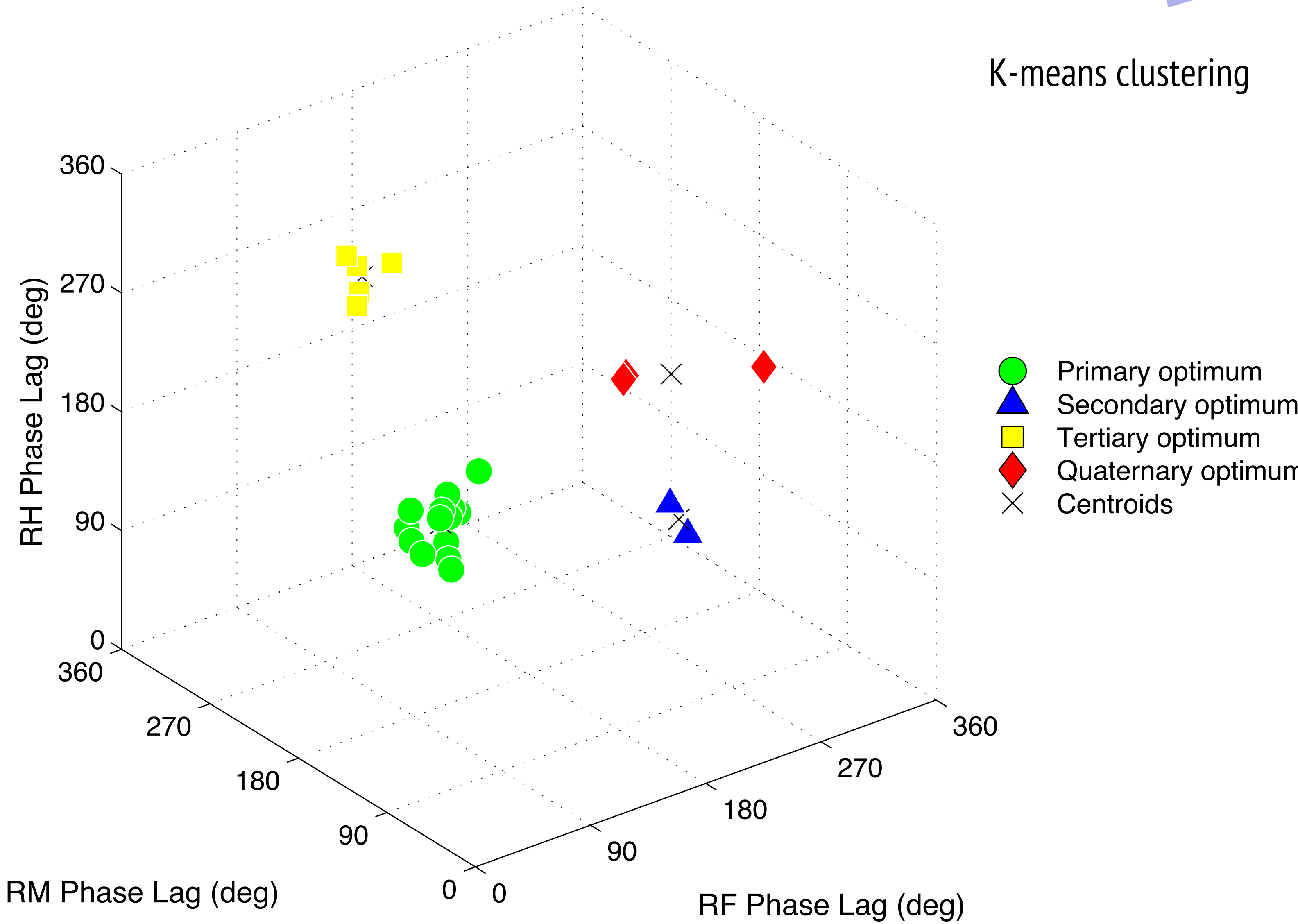
OPTIMIZATION

LIS



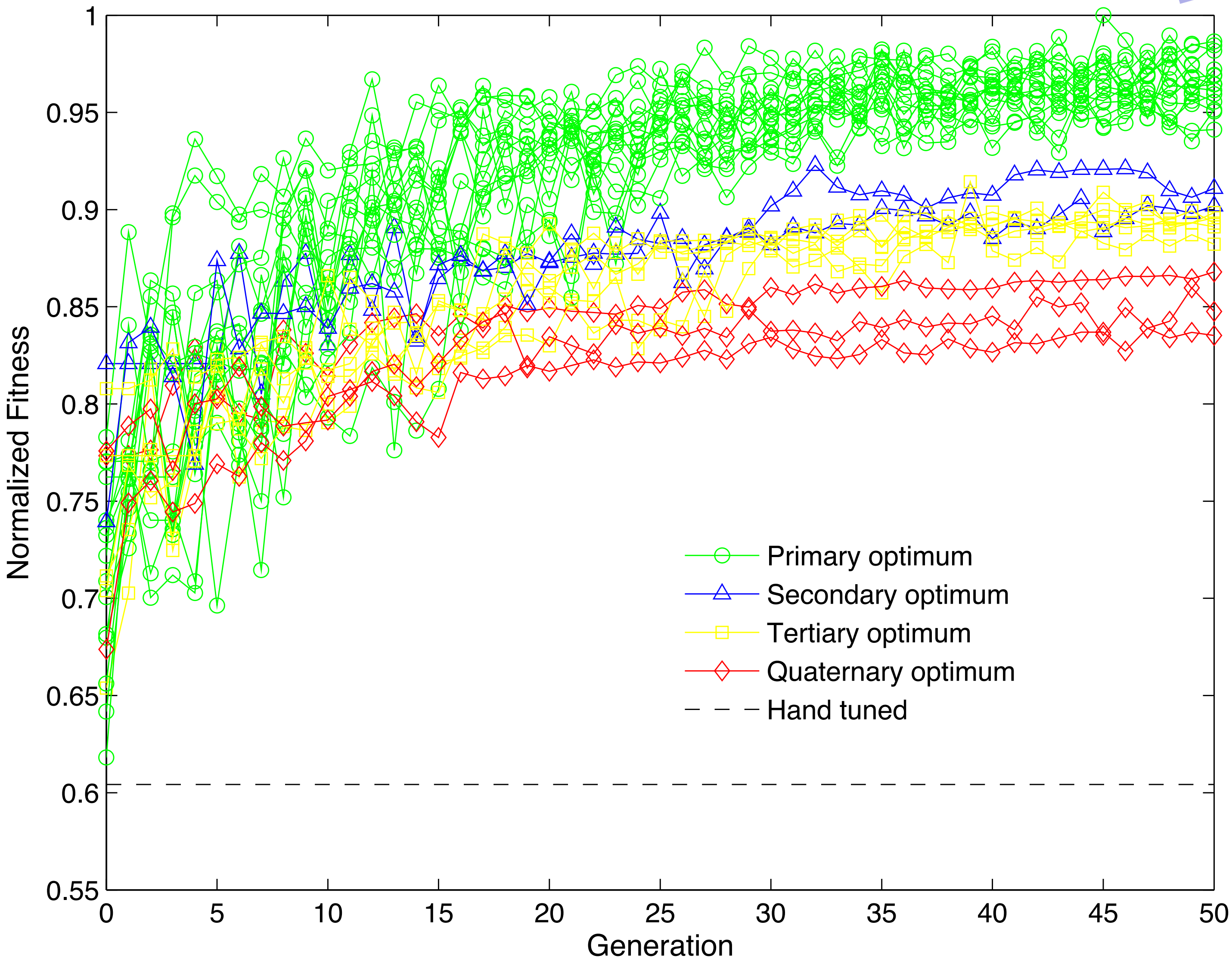
OPTIMIZATION

K-means clustering

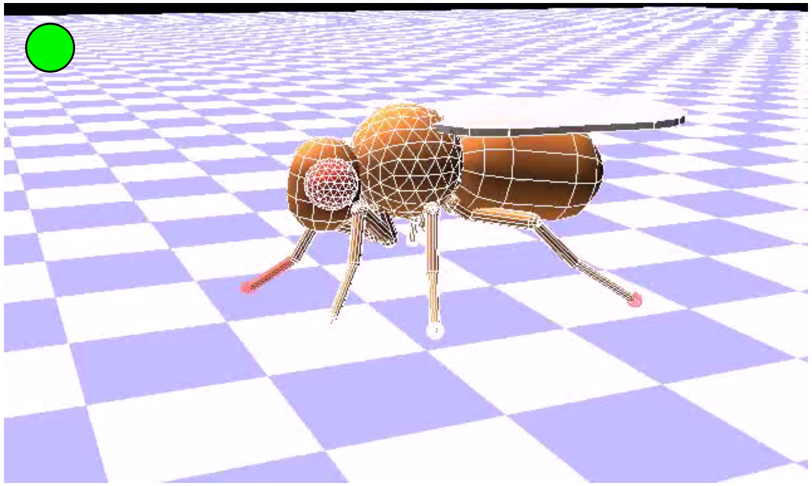


OPTIMIZATION

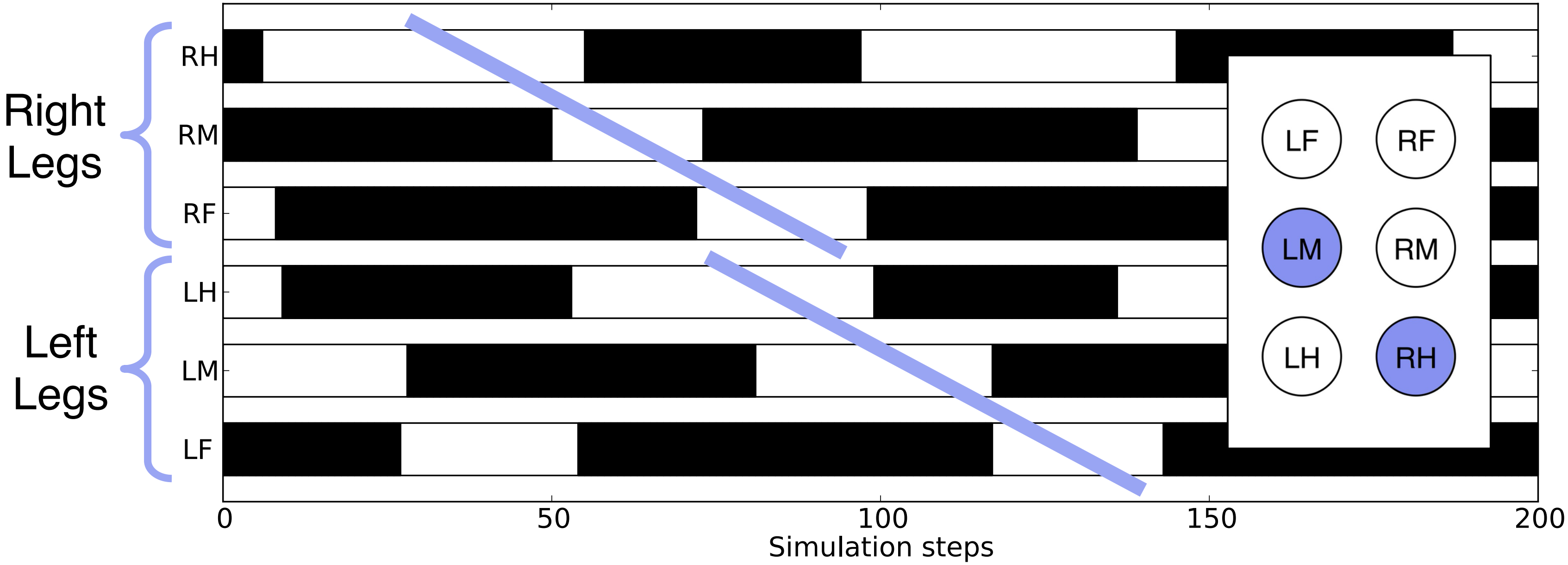
Best particle for each of 25 runs:



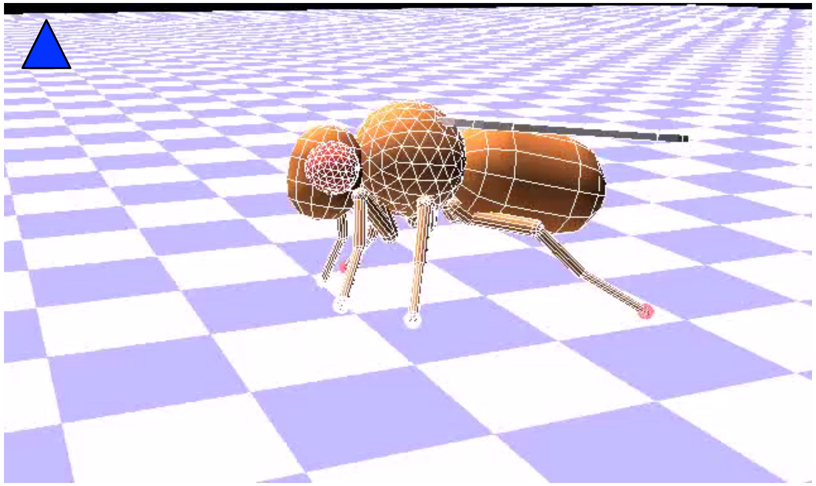
OPTIMIZATION



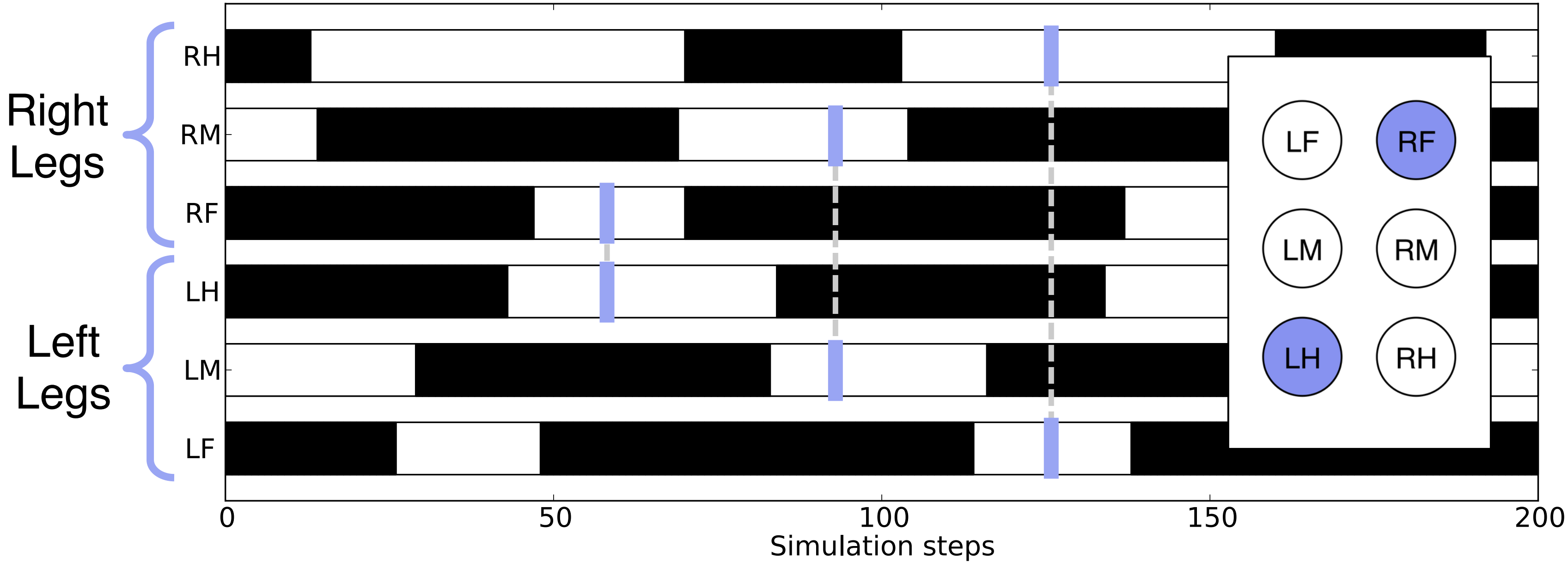
- Primary optimum
  - Ripple-like gait
  - Normalized fitness: 1.00
  - Found in 60% of runs



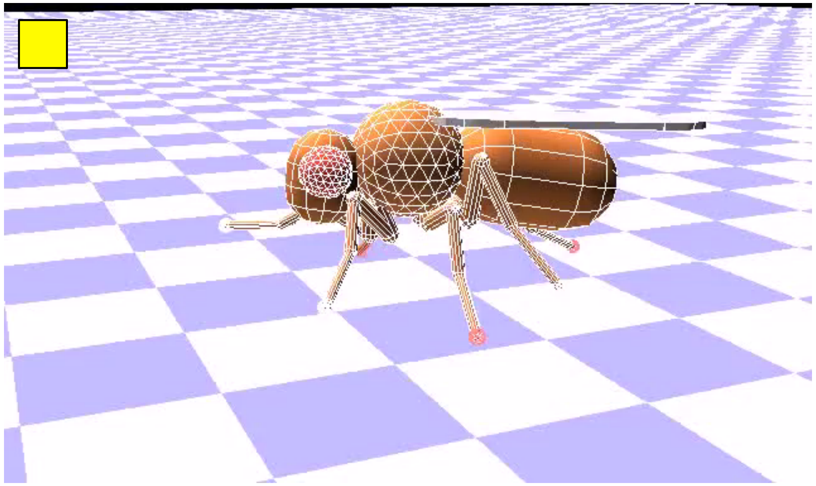
OPTIMIZATION



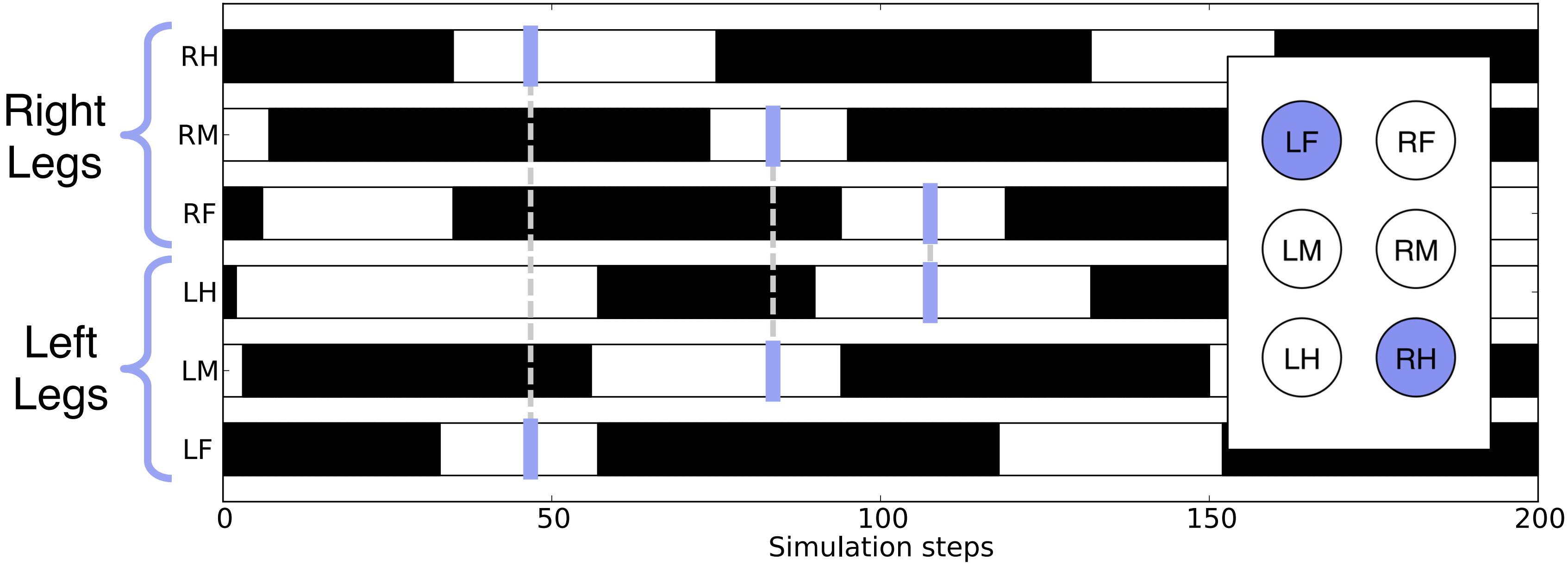
- Secondary optimum
  - Trot-like gait
  - Normalized fitness: 0.92
  - Found in 8% of runs



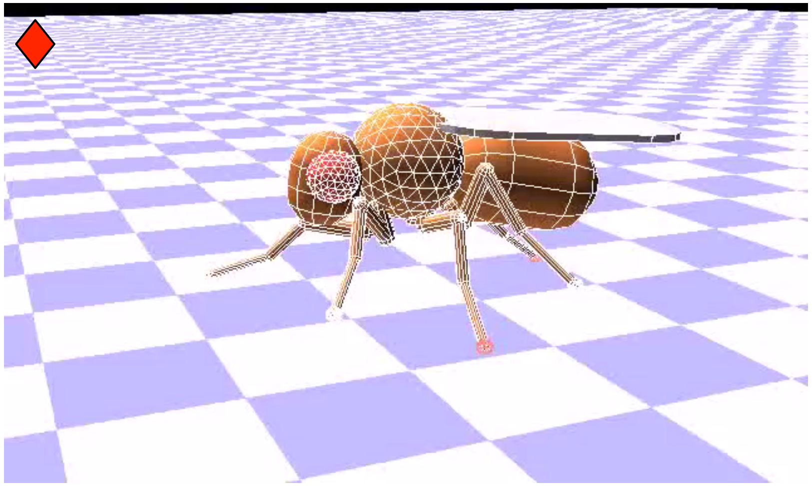
OPTIMIZATION



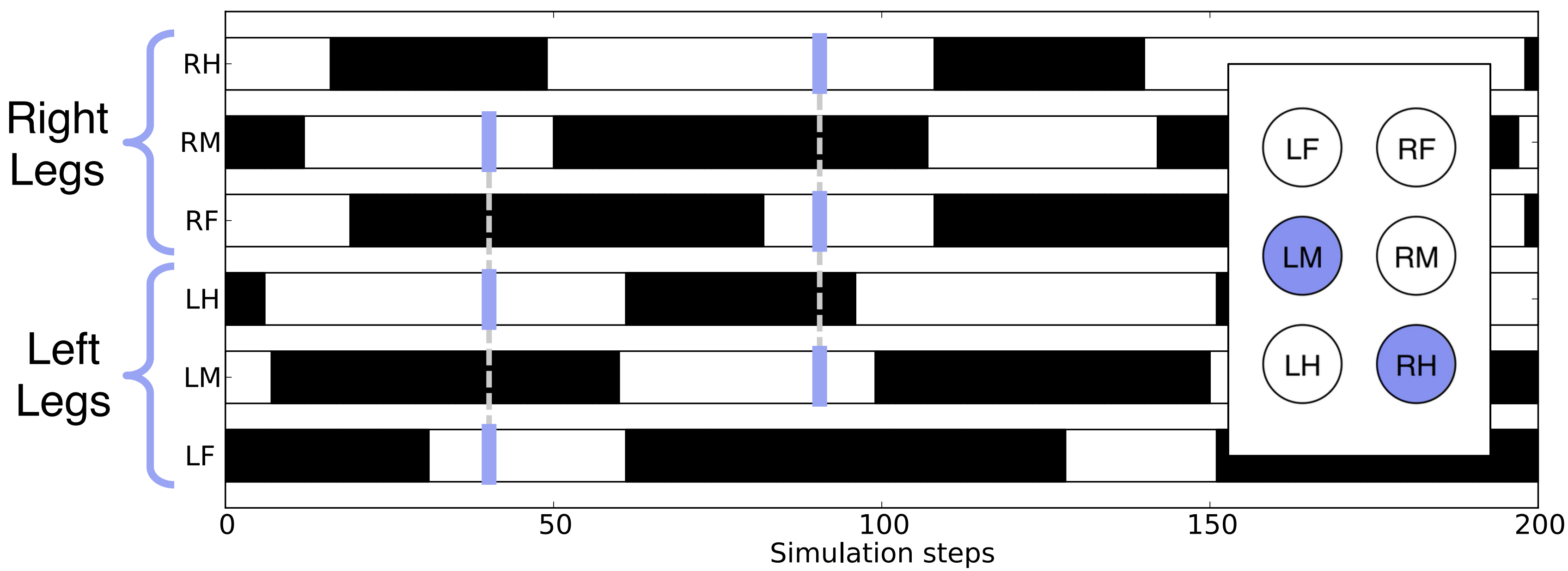
- Tertiary optimum
  - Alternate trot-like gait
  - Normalized fitness: 0.91
  - Found in 20% of runs



OPTIMIZATION



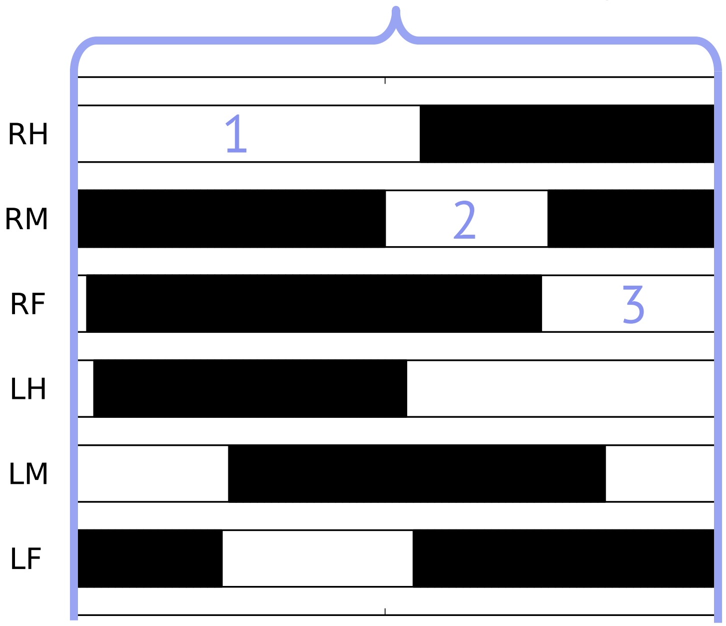
- Quaternary optimum
  - Alternating tripod-like gait
  - Normalized fitness: 0.87
  - Found in 12% of runs



SUMMARY

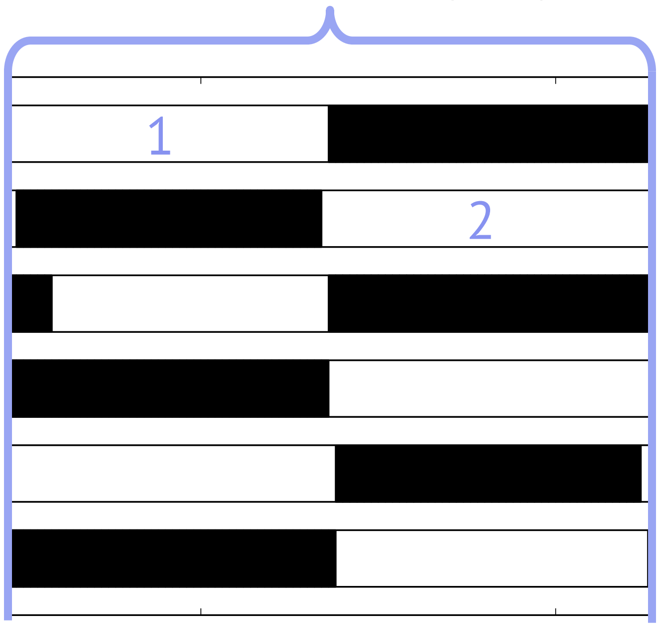
- Evolved gaits differ from biological walks
- Hand-tuned/biological
  - Alternating tripod gait
  - Normalized fitness: 0.61

One oscillation of optimized gait

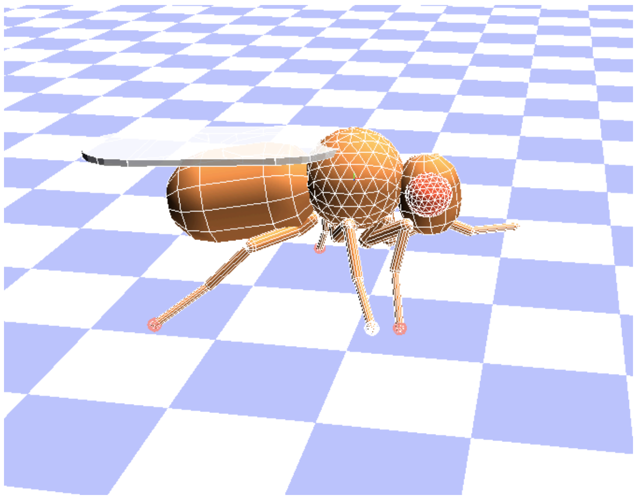


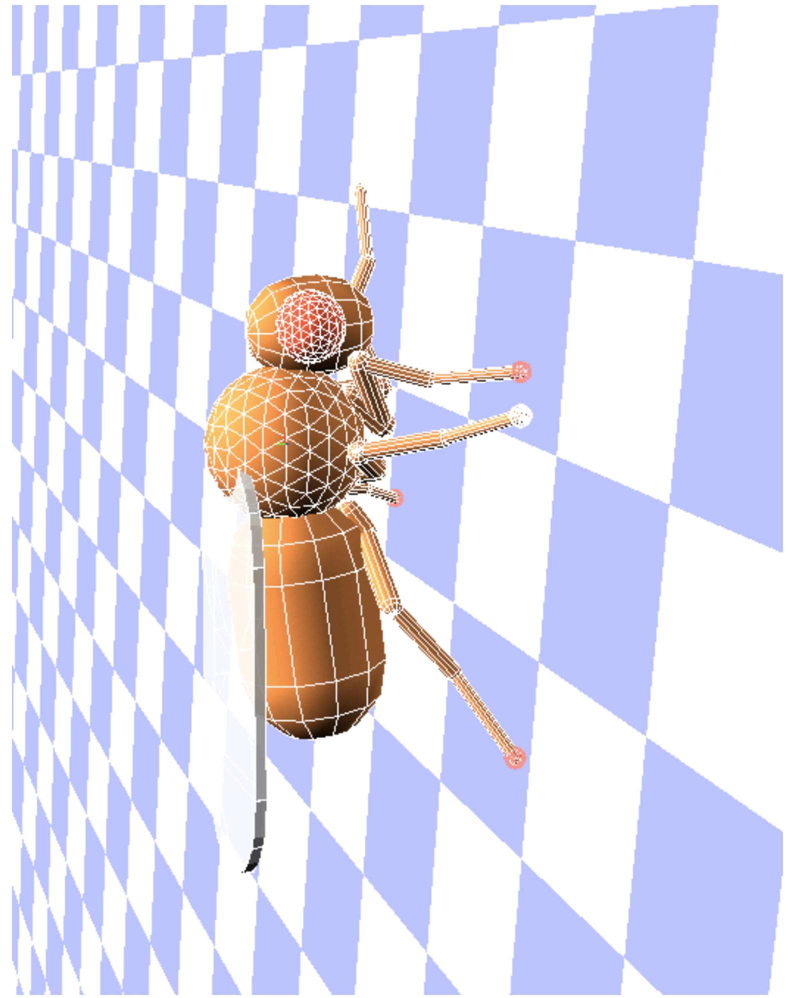
vs

One oscillation of biological gait



FUTURE WORK





- Claw adhesion
- Improved fitness function to incorporate stability, energy consumption, and/or maneuverability

THANKS

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Pavan Ramdya

Andrea Maesani

QUESTIONS

REFERENCES

- Cruse, Holk, et al. *Insect walking is based on a decentralized architecture revealing a simple and robust controller*. Philosophical Transactions of the Royal Society, 2007.
- Cruse, Holk, et al. Walknet-a biologically inspired network to control six-legged walking. Neural Networks 11 (7- 8), 1998.
- Ekeberg, Orjan, et al. *Dynamic simulation of insect walking*. Arthropod structure & development, 33 (3), 2004.
- Ferrell, Cynthia. *Robust Agent Control of an Autonomous Robot with Many Sensors and Actuators*. PhD thesis, 1993.
- Schmitz, Josef, et al. *A biologically inspired controller for hexapod walking: simple solutions by exploiting physical properties*. The Biological Bulletin, 2001.
- Soler, Cédric, et al. *Coordinated development of muscles and tendons of the Drosophila leg*. Development, 2004.
- Sink, Helen. *Muscle Development in Drosophila*. 2006.
- Stick insect image: http://www.prlog.org/10270774-stick-insect.jpg

PLAN

Build model

Explore control

Tasks	W1 (2/24)	W2 (3/2)	W3 (3/9)	W4 (3/16)	W5 (3/23)	W6 (3/30)	W7 (4/6)	W8 (4/13)	W9 (4/20)	W10 (4/27)	W11 (5/4)	W12 (5/11)	W13 (5/18)	W14 (5/25)	W15 (6/1)
Literature Review															
Fly anatomy															
CPG literature															
Optimizers															
Experiments															
Familiarize with Webots															
High speed camera work															
Kinematic analysis															
Build simple 3D model								B							
Hand-tune basic controller								R							
Integration into Optimizer								E							
Optimization experiments								A							
Analysis of optimization experiments								K							
Documentation															
Midterm presentation															
Final presentation															
State of the Art															
Methods															
Results															
Intro and Conclusion															
Review															