Morphological Change in Machines Accelerates the Evolution of Robust Behavior

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Bio-inspired Robotics: Replicate the **products** of evolution.
Bio-inspired Robotics: Replicate the *products* of evolution.

Evolutionary Robotics: Replicate the *process* of evolution.
Offspring with genetic variation

Less fit organisms die

More fit organisms survive and reproduce

BIOLOGICAL EVOLUTION
Offspring with genetic variation

Less fit organisms die

More fit organisms survive and reproduce

BIOLOGICAL EVOLUTION

THE GENETIC ALGORITHM

Generate random solutions

Discard poor solutions

Make modified copies of the better solutions
Offspring with genetic variation

Less fit organisms die

More fit organisms survive and reproduce

Generate random solutions

Discard poor solutions

Make modified copies of the better solutions

BIOLOGICAL EVOLUTION

EVOLUTIONARY ROBOTICS

Evolutionary Robotics
How an evolutionary approach to robotics provides an engineering benefit
Proximate and Ultimate Mechanisms of Behavior

- **emergence**
  - **ontogenetic**
    - intermediate term lifetime of individual
    - learning and developmental mechanisms
  - **phylogenetic**
    - very long term generations
    - encoding in genome evolutionary algorithm morphogenesis

- "here and now" short-term
  - dynamical system behavioral mechanisms

Arrows indicate the flow from proximate to ultimate mechanisms.
Morphological scaffolding

Evolutionary Time

Development Time

No Morphological Scaffolding

Morphological Scaffolding
Day 1 - Egg
Day 3-4 - Tailbud
Day 6 - Tadpole with External Gills
Day 9 - Tadpole with Internal Gills
Day 12 - Tadpole with operculum
Day 70 - Tadpole with Hindlimbs
Day 84 - Tadpole with forelimbs
Day 84+ - Tadpole metamorphosis
Day 84+ - Young Frog
Morphological scaffolding

Quadruped Parametric Body Change

- Graph showing Robot Evaluations vs. Turning Angle (rad)
- Diagrams of configurations a to i
  - Configuration a
  - Configuration b
  - Configuration c
  - Configuration d
  - Configuration e
  - Configuration f
  - Configuration g
  - Configuration h
  - Configuration i
Morphological scaffolding

Phylogenetic, Topological change

Phylogenetic, Ontogenetic, Topological change

No phylogenetic, ontogenetic Physiological change
Morphological scaffolding
Morphological scaffolding