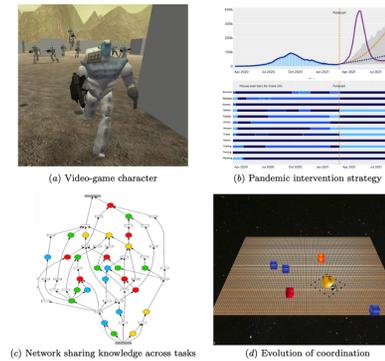# Introduction

Risto Miikkulainen

February 21, 2026

Introduction to Neuroevolution

- ▶ Neuroevolution: Optimization of neural network designs through evolutionary computation.
- ▶ Approach: Not just about optimizing a single metric but solving complex, multi-objective problems.
- ▶ Focus: Discovering creative, adaptable solutions that can operate in dynamic environments.

(a) Video-game character   (b) Pandemic intervention strategy

(c) Network sharing knowledge across tasks   (d) Evolution of coordination

Illustrative opportunities for neuroevolution.

Challenge 1: Designing a Video Game Character

- ▶ Scenario: Creating a search-and-rescue sidekick in a video game.
- ▶ Requirements: Anticipate player's needs, act in a human-like manner, manage limited resources.
- ▶ Difficulty: Many behaviors are hard to define but must feel natural and believable.


(http://nerogame.org)

Challenge 2: Pandemic Intervention Strategy

- ▶ Scenario: A new pandemic requires immediate, tailored intervention strategies.
- ▶ Problem: Strategies must adapt to different regions and changing circumstances.
- ▶ Difficulty: General rules may not be effective; customization is key.

(https://evolution.ml/demos/npidashboard/)
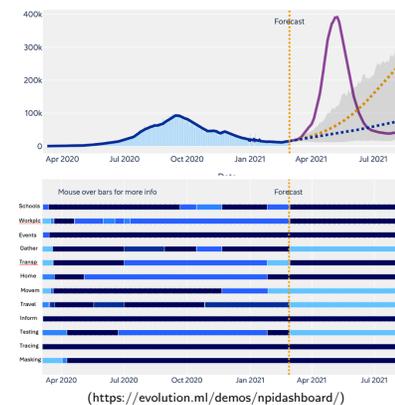
Challenge 3: Retail Sales Prediction

- ▶ Scenario: Predicting sales across various stores with limited data.
- ▶ Problem: Traditional deep learning struggles with small datasets.
- ▶ Solution: Leveraging data from other domains to improve predictions.
- ▶ Goal: Generalize beyond the small dataset to minimize waste and optimize inventory.
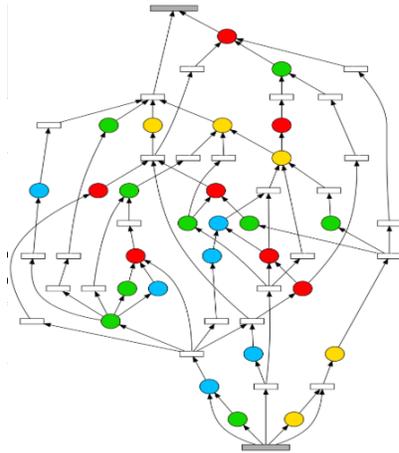
(https://evolution.ml/demos/ctr/)
Network sharing knowledge across tasks.

Challenge 4: Evolution of Coordination in Hyenas

- ▶ Scenario: Biologists observe sophisticated coordination among hyenas.
- ▶ Question: Could this be an evolutionary adaptation indicating a leap in social intelligence?
- ▶ Solution: Simulate the evolutionary process to understand how such behaviors emerge.
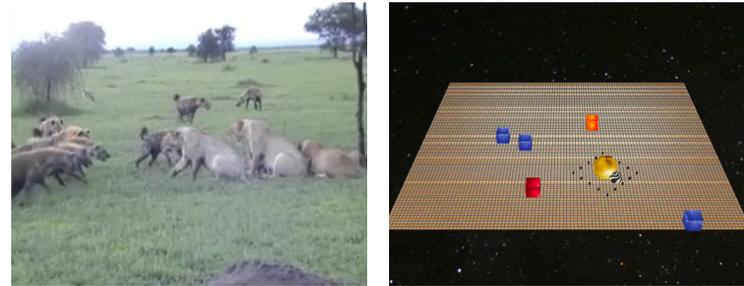
(https://nn.cs.utexas.edu/?mobbingfactors)
Simulating the evolution of coordination in hyenas.

Key Insight: Neuroevolution in Action

- ▶ Neuroevolution is not just about optimizing known metrics.
- ▶ It's about discovering creative, effective solutions that can adapt to complex, dynamic environments.
- ▶ Examples illustrate how neuroevolution can address a wide range of challenges.

- ▶ Not just about replacing human creativity, but extending it.
- ▶ Potential to improve decision-making in engineering, science, and society.
- ▶ Neuroevolution is a powerful tool in the AI toolbox.

(a) Video-game character   (b) Pandemic intervention strategy
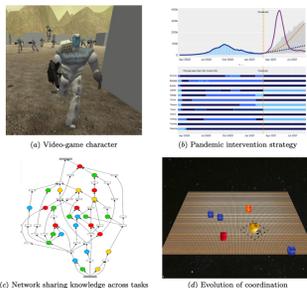
(c) Network sharing knowledge across tasks   (d) Evolution of coordination

How Does Neuroevolution Work?

- ▶ Start with a population of randomly initialized neural networks.
- ▶ Evaluate each network's performance on a specific task.
- ▶ Select the top-performing networks to serve as parents for the next generation.
- ▶ Use crossover and mutation to generate new networks from these parents.
- ▶ Repeat the process until the networks evolve to meet the task's needs.
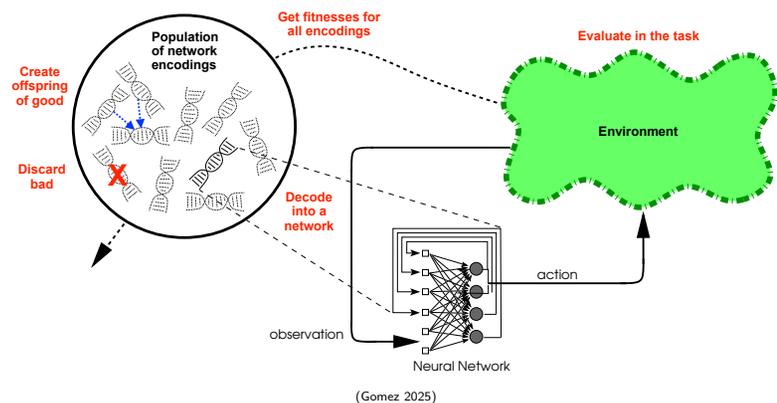
(Gomez 2025)

Advantages of Neuroevolution

- ▶ Beyond Backpropagation: Does not rely on gradient information; useful for tasks with non-differentiable objectives.
- ▶ Systematic Evolution: Builds on successful strategies while still allowing for random exploration.
- ▶ Creative Exploration: Able to explore a wide range of potential solutions.

(Gomez 2025)
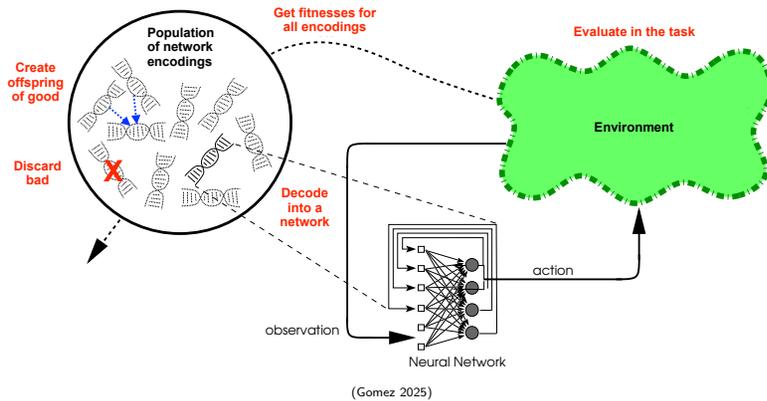
Creativity: A Paradigm Shift in AI

- ▶ AI is transitioning from **prediction** to **prescription**.
- ▶ Moving beyond imitation to **creating new solutions**.
- ▶ Enabler 1: Availability of massive amounts of data from text, code, images, and more.
- ▶ Enabler 2: Exponential increase in computational power.
- ▶ Examples include generating images, writing prose, and creating new molecules.
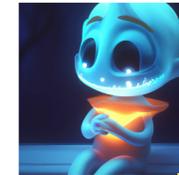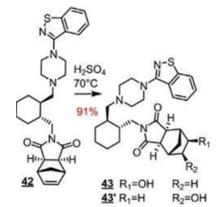

"Infite joy"
(NYTimes 8/22/22)

(https://chatgpt.com)

Large Language Models (LLMs)

- ▶ LLMs scale up neural network training to unprecedented levels.
- ▶ Transformational in encoding general knowledge about the world.
- ▶ Capable of performing a wide range of tasks, often with human-like competence.

(Alammar 2018)
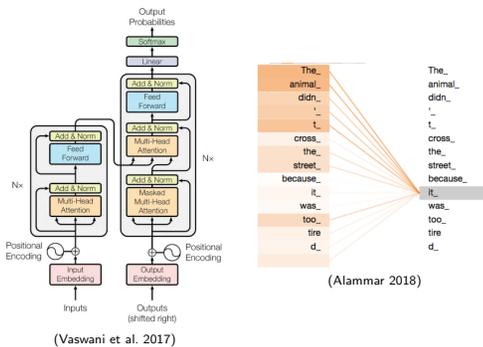
(Vaswani et al. 2017)

Tell me a joke about Cognizant.

Why did the Cognizant employee bring a ladder to work?
Because they heard there were lots of opportunities for climbing the corporate ladder at Cognizant!

The Transformer Architecture.

Image Generation Models

- ▶ Techniques like diffusion models enable AI to generate novel images.
- ▶ Systems learn general principles about the visual world.
- ▶ Extends to video and sound, encoding knowledge about objects, relationships, and styles.
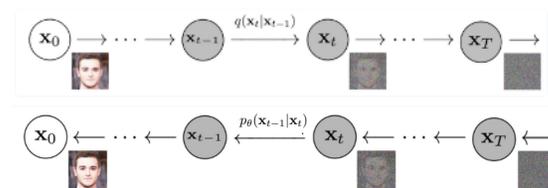
(Ho et al. 2020)

teddy bears working on new AI research on the moon in the 1980s
(@BecomingCritter, X 4/6/22)

The Diffusion Architecture.

The Emergence of Decision AI

- ▶ AI now drives decision-making in behavior, design, and strategy.
- ▶ Examples include autonomous agents, optimized designs, and strategic recommendations.
- ▶ Unlike other methods, it is based on **search** rather than pattern recognition.

Decision-making AI explores new solutions.

Challenges in Decision AI

- ▶ Traditional methods like reinforcement learning (RL) rely on hill-climbing.
- ▶ This approach limits exploration and creativity.
- ▶ Struggles with high-dimensional, nonlinear, and deceptive search spaces.
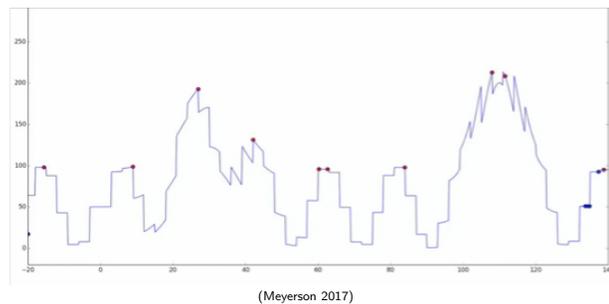

(https://deap.readthedocs.io/en/stable/api/benchmarks.html)
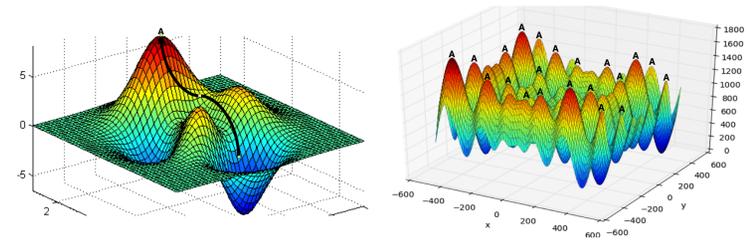
Limitations of hill-climbing in Decision AI.

Evolution's Role in Creative AI

- ▶ Evolution offers a population-based search approach.
- ▶ Allows for exploration across a wide search space.
- ▶ Combines good solutions through crossover, accelerating discovery.
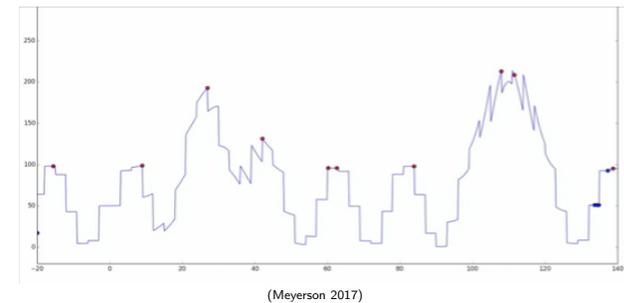

(Meyerson 2017)

Population-based search.

Evolution Makes Scale-up Possible

- ▶ In space: solutions to 70-bit multiplexer ($2^{2^{70}}$ space)
- ▶ In dimensionality: 1B dimensions possible
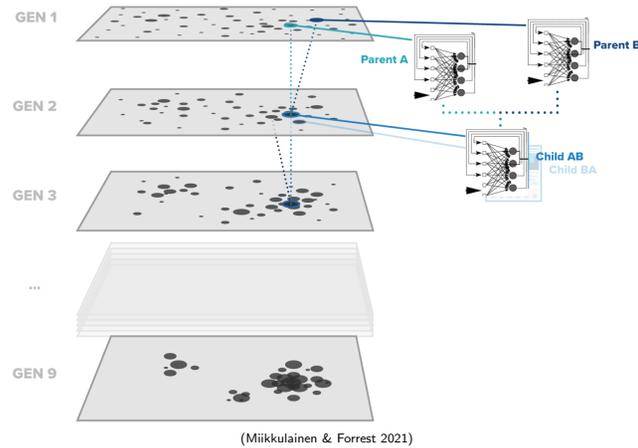- ▶ In complexity: get around deception with novelty and multiobjectivity

(Meyerson 2017)

Illustration of Population-based Search

- ▶ Population-based search explores diverse solutions.
- ▶ Allocates resources to most promising areas.
- ▶ Discovers multiple alternative solutions

(Miikkulainen & Forrest 2021)

How Does Neuroevolution Improve the World?
1. Optimizing Intelligent Agents

- ▶ Neuroevolution optimizes behavior for intelligent agents in dynamic environments.
- ▶ Applications:
  - ▶ Control systems for cars, planes, and robots.
  - ▶ Non-player characters in simulated worlds.
 - ▶ Strategies for logistics, manufacturing, and smart cities.

(http://nerogame.org)

2. Customizing Decision-Making Strategies

- ▶ Neuroevolution discovers tailored solutions for decision-making.
- ▶ Applications:
  - ▶ Personalized wellness and healthcare plans.
  - ▶ Customized marketing and investment strategies.
 - ▶ AI for Good: Pandemic mitigation, climate change strategies, and more.
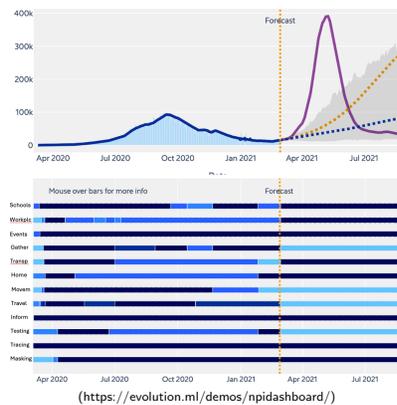
(https://evolution.ml/demos/npidashboard/)

3. Optimizing Other Learning Methods

- ▶ Neuroevolution optimizes designs for other AI methods.
- ▶ Applications:
  - ▶ Enhancing deep learning, reinforcement learning, and neuromorphic computing.
  - ▶ Evolving architectures and functions for specific tasks and hardware.
  - ▶ Combining multiple datasets to improve learning when data is sparse.
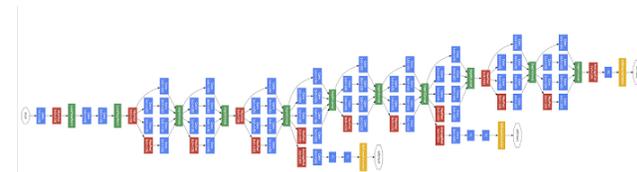
(Szegedy et al. 2016)

4. Understanding Biological Behavior

- ▶ Neuroevolution provides insight into biological processes.
- ▶ Applications:
  - ▶ Studying the evolution of behaviors like mating, hunting, and communication.
  - ▶ Modeling the emergence of language and intelligence.
  - ▶ Inspiring designs for effective and resource-efficient AI systems.

(https://nn.cs.utexas.edu/?mobbingfactors)

Conclusion: The Role of Neuroevolution

- ▶ Extending Creativity: Neuroevolution expands the creative potential of AI, enabling the discovery of novel and effective solutions.
- ▶ Solving Complex Problems: It excels in optimizing behavior, decision-making, and learning in dynamic, real-world environments.
- ▶ Bridging Biology and AI: Provides insights into biological processes, offering inspiration for more efficient and robust AI designs.
- ▶ Impact on Society: Neuroevolution has far-reaching applications, from optimizing intelligent systems to solving global challenges like climate change and healthcare.

(Gomez 2025)