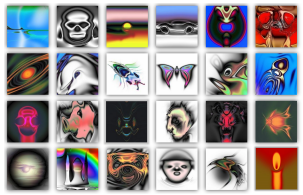
Collaborative Neuroevolution Overview

- NERO allowed players to shape the evolution of their teams.
- However, it did not enable collaboration among multiple players.
- Collaborative Neuroevolution allows multiple users to build on others' discoveries.
- Examples include Picbreeder and other games using Procedural Content Generation (PCG).

(http://nerogame.org)

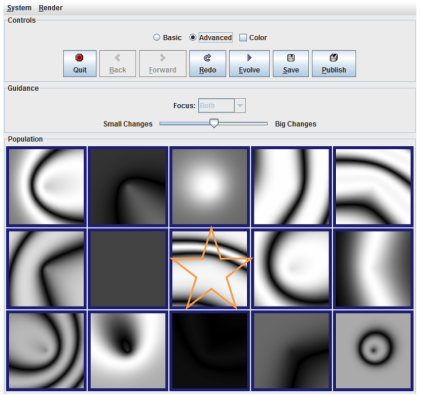


(Stanley 2014)

(Risi et al. 2016)

Picbreeder: Collaborative Image Evolution

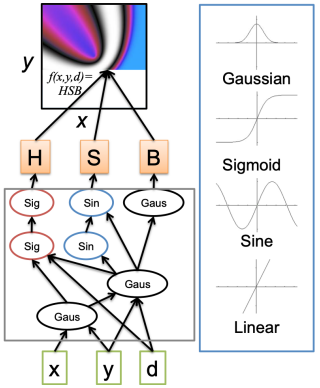
- Picbreeder is an interactive evolutionary art tool.
- Users evolve images by selecting the ones they like best.
- Each selected image generates offspring through crossover and mutation.
- Users can branch off from the evolved images of others.



(Stanley 2014)

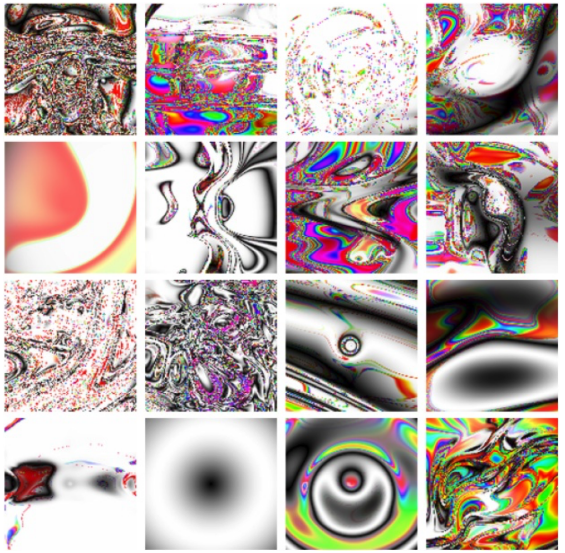
Picbreeder Image Representation

- Images are represented by CPPNs (compositional pattern-produting networks)
- CPPNs are evolved with NEAT
- A composition of simple functions, complexification of topology



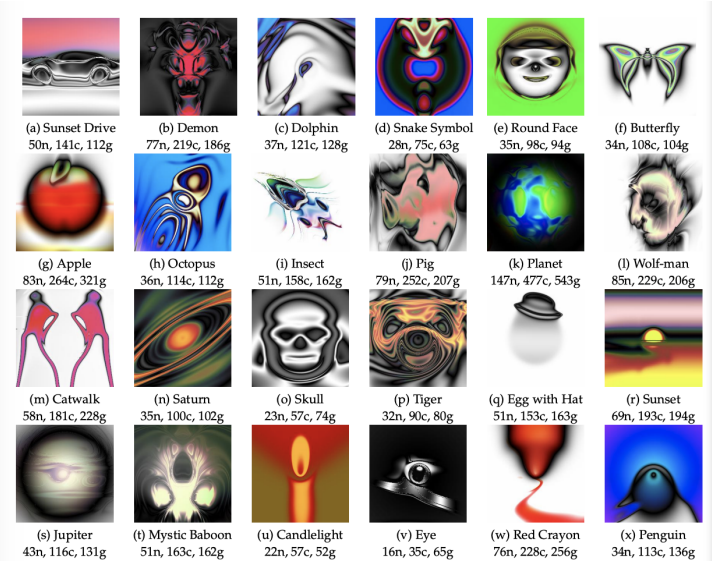
(Stanley 2014)

Random CCPNs Aren't Very Artistic...



(Stanley 2014)

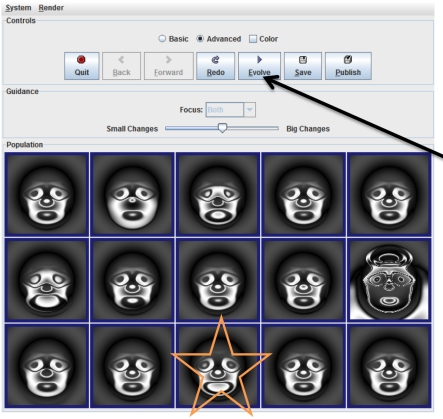
...But Collaborative Interactive Evolution Finds Interesting Images



(Secretan et al. 2011)

How Users Breed Images

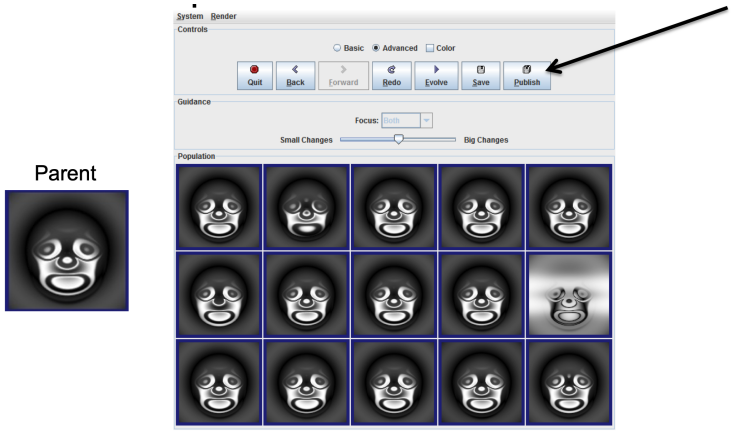
- E.g. branching from the face image:
- Select a parent, then evolve



(Stanley 2014)

How Users Breed Images

- The next generation will appear
- Repeat until satisfied, then publish

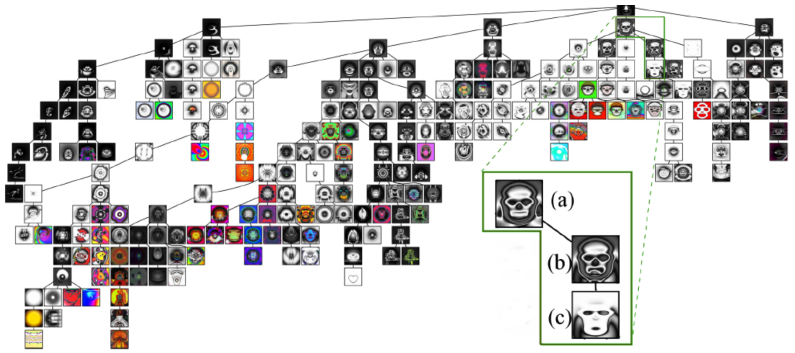


(Stanley 2014)

Demo link: `https://nbenko1.github.io`

Collaborative Image Evolution Results

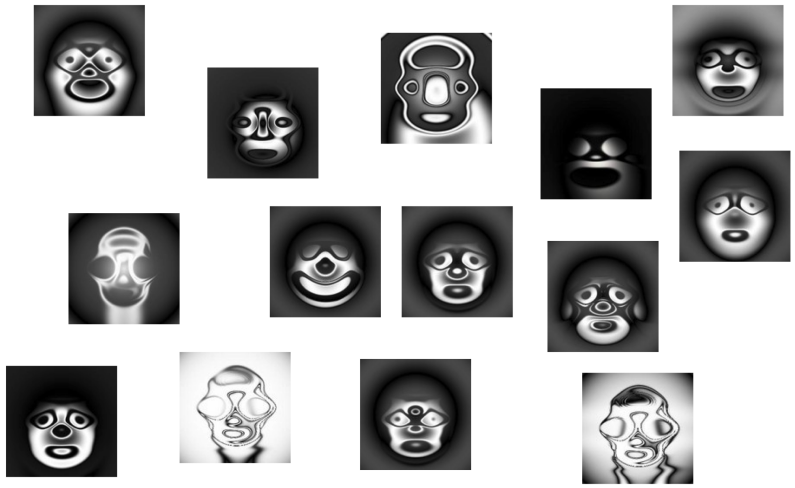
- Collaboration helps explore larger parts of the design space.
- Users build upon each other's discoveries
- Some users aim for specific targets (e.g., animals), while others explore freely.



(Stanley 2014)

Entire Species Emerge

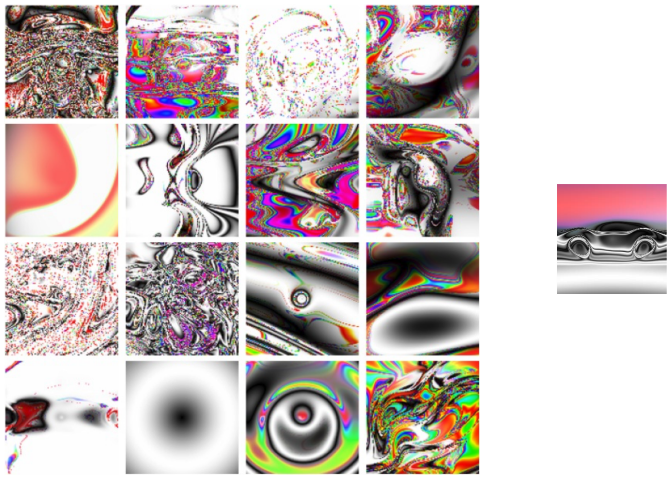
E.g. spooky faces:



(Stanley 2014)

Process of Discovery

- E.g. how can you find a car in the space of images?
- Stepping stones and branching are essential



(Stanley 2014)

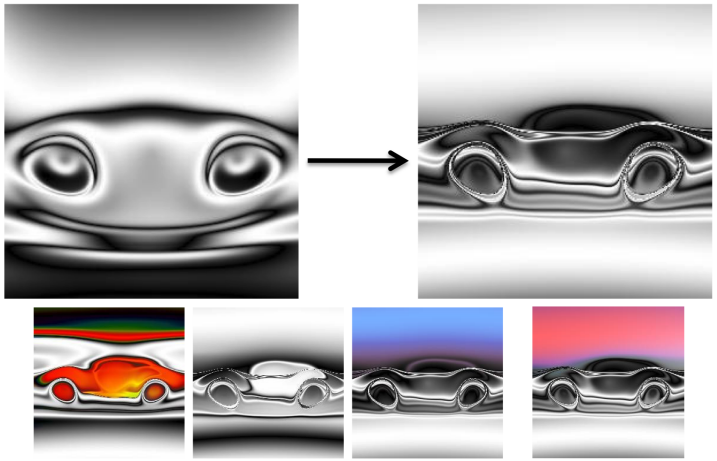
Branching on a stepping stone

- Someone else had evolved what looked like ET's face
- Trying to evolve variations of it...

(Stanley 2014)

Branching on a stepping stone

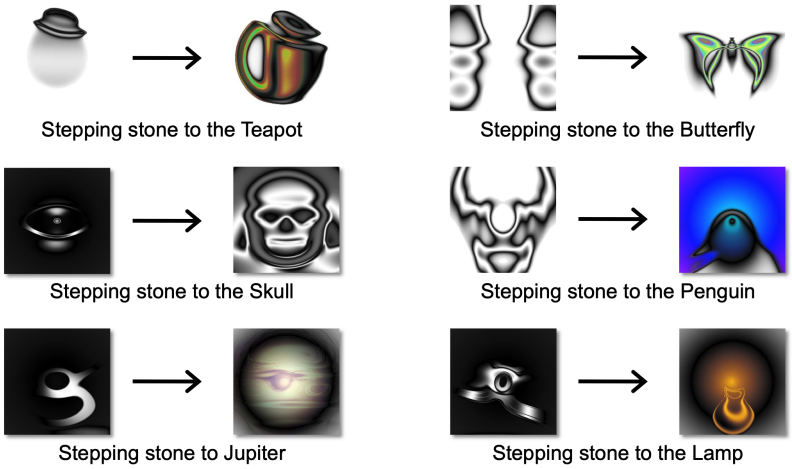
- ...the eyes descended and started to look like a car
- Cool, let's evolve car variations instead!



(Stanley 2014)

Collaborative interactive discovery

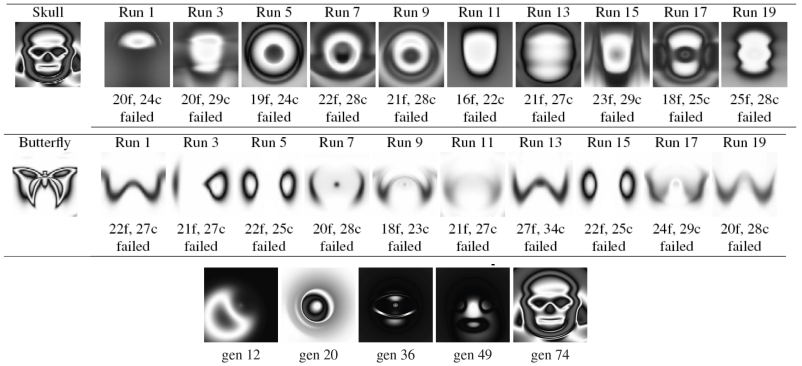
- Most interesting images have similar histories:
- They are found collaboratively through stepping stones



(Stanley 2014)

Re-evolving Complex Images

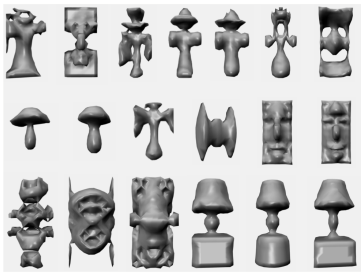
- Direct evolution towards a target does not work
- Stepping stones and branching are essential
- Foundation for novelty search



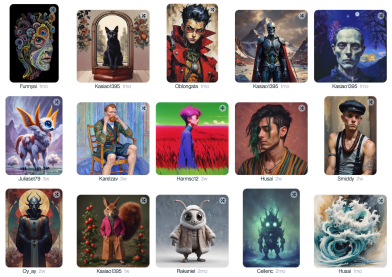
(Stanley 2014)

Extending Picbreeder's Idea

- EndlessForms extends Picbreeder to 3D objects.
- Artbreeder combines Picbreeder with generative AI models like GANs.
- Collaborative Neuroevolution can be applied to non-visual artifacts like music or other content.



(Clune et al. 2012)



(https://www.artbreeder.com)

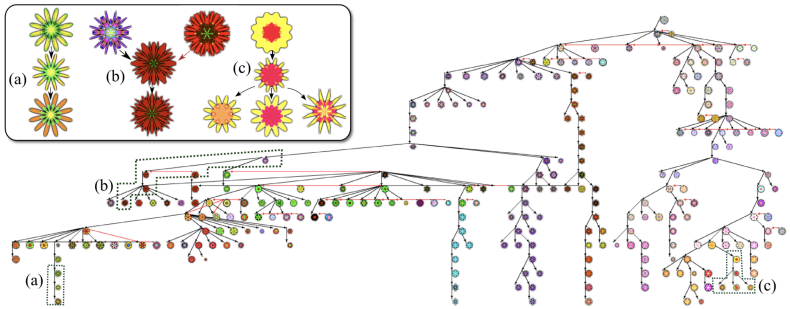
Evolving Game Content with Procedural Content Generation (PCG)

- PCG enables the creation of game content algorithmically.
- Examples: Petalz and Galactic Arms Race (GAR).
- Players evolve game elements collaboratively, such as flowers in Petalz or particle weapons in GAR.

(Risi et al. 2016)

Collaborative Evolution in Petalz

- Petalz allows players to breed and trade procedurally generated flowers.
- Players decorate balconies and share seeds in a digital marketplace.
- Collaborative interactions link players through flower breeding and seed exchanges.

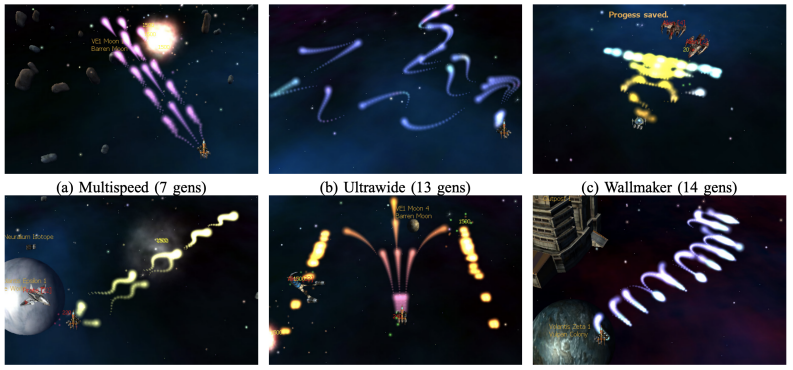


(Risi et al. 2016)

Demo link: `https://youtu.be/GgFUlpM3XIc`

Galactic Arms Race: Collaborative Weapon Evolution

- Players pilot spaceships and acquire procedurally generated weapons.
- Weapons evolve based on implicit feedback from players.
- Weapon diversity evolves through particle-based CPPNs.



(a) Multispeed (7 gens) (b) Ultrawide (13 gens) (c) Wallmaker (14 gens)

(d) Corkscrew (3 gens) (e) Tunnelmaker (2 gens) (f) Blue Ladder (42 gens)

(Hastings et al. 2009)

Demo link: `https://youtu.be/N8q2uOwWcFc`

Successes of Collaborative Neuroevolution

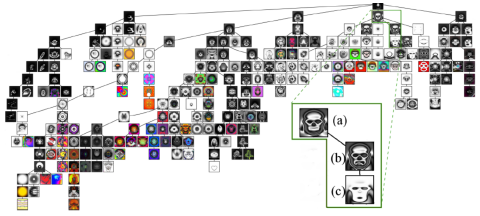
- Petalz and Galactic Arms Race showcase creative, user-driven content evolution.
- Petalz had over 1,900 users and 38,646 evolved flowers.
- Galactic Arms Race attracted over 1,000 players in two months, evolving 379,081 weapons—a big success in the 2009 scale.
- These examples highlight the potential of collaborative procedural content generation.

(Risi et al. 2016)

(https://youtu.be/N8q2uOwWcFc)

Research and Future Opportunities

- Collaborative NE allows users to explore a wide variety of solutions.
- Systems like Picbreeder inspired novelty search, i.e. an automated exploration method.
- Future research can explore how collaborative evolution impacts emergent properties.
- Potential applications: generative design, artistic exploration, dynamic game worlds.



(Stanley 2014)

Challenges of Interactive Evolution

- Interactive evolution requires significant human effort.
- Some domains are inherently rewarding, but others may lead to user fatigue.
- In abstract domains, progress is less obvious, making it hard to maintain engagement.
- How can we make human contributions more practical and sustainable?


(http://nerogame.org)

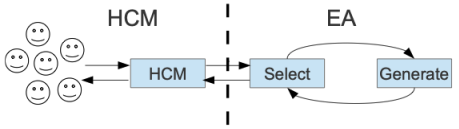

(Stanley 2014)


(Risi et al. 2016)


(https://youtu.be/N8q2uOwWcFc)

Using Human Computation Markets (HCM)

- HCM platforms like Amazon Mechanical Turk can help in three ways:
  - Bootstrap experiments to make them more engaging.
  - Evaluate different designs.
  - Extend experiments over long periods of time.
- Monetary rewards substitute for intrinsic interest in abstract tasks.
- Computational budget shifts from cloud computation to human computation.



(Lehman & Miikkulainen 2013)

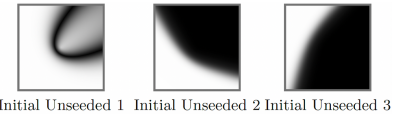
Seeding Interactive Evolution with HCM

- Early stages of interactive evolution may be uninteresting to users.
- Example: In Picbreeder, initial images are simple geometric shapes.
- HCM can guide early evolution to more complex forms.
- Once images become appealing, human creativity can take over.


(Lehman & Miikkulainen 2013)

Boring initial images Interesting initial images

Seeding Leads to More Complex Solutions


Initial Unseeded 1 Initial Unseeded 2 Initial Unseeded 3


Final Unseeded 1 Final Unseeded 2 Final Unseeded 3


Initial Seeded 1 Initial Seeded 2 Initial Seeded 3


Final Seeded 1 Final Seeded 2 Final Seeded 3

(Lehman & Miikkulainen 2013)

Long-Running Experiments with HCM

- Some experiments require extended runs to achieve interesting results.
- Users may fatigue or lose interest over long periods.
- HCM provides a continuous stream of transient users.
- Even inconsistent contributions can guide evolution, as noise in evaluations may encourage exploration.


(http://nerogame.org)


(Stanley 2014)


(Risi et al. 2016)


(https://youtu.be/N8q2uOwWcFc)

Conclusion: Making Human Contributions Practical

- Human computation markets can help bootstrap, evaluate, and extend experiments.
- They allow for scaling interactive evolution in domains where human creativity is difficult to harness.


(http://nerogame.org)


(Stanley 2014)


(Risi et al. 2016)


(https://youtu.be/N8q2uOwWcFc)

Conclusion: Interactive Neuroevolution

- **Why Interactive Neuroevolution is Useful**
  - Solves the problem of complex and multifaceted objectives that are difficult to formalize.
  - Combines human intuition and evolutionary processes to guide neuroevolution more effectively.
  - Enables open-ended discovery of solutions that are surprising and innovative.
- **Key Successes**
  - NERO: Evolving intelligent behaviors in real-time, interactive environments.
  - Picbreeder: Collaborative image evolution, leading to diverse and creative outcomes.
  - Petalz and Galactic Arms Race: Collaborative Procedural Content Generation (PCG) in games.
- **Future Opportunities**
  - Combining human guidance with pre-trained networks to enhance efficiency.
  - Extending interactive neuroevolution to more domains, such as music, art, and engineering.
  - Incorporating adaptive human interaction, where systems request advice when needed.
  - Using Human Computation Markets (HCM) to scale and sustain long-term experiments.