# Open-ended Agent Learning in the Era of Foundation Models

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Senior Research Advisor DeepMind

- Motivate
  - Quality-Diversity algorithms
  - Open-ended algorithms
  - Al-generating algorithms
- Discuss new possibilities unlocked by "foundation models"

Aka LLMs, LMs, VLMs, Generative AI, Frontier models, GPT, pretraining, etc. 



# Al Safety

- An important topic
- One I take seriously, and encourage you to as well
- - Clune 2019, AI-Generating Algorithms
  - ended AI: Tensions Between Control and Creativity
- This talk is not on safety (requires its own focus)
  - But please ask questions

• Bengio, Hinton, et al. 2024, Managing Al Risks in an Era of Rapid Progress. Science

## There are unique safety issues for AI-GAs and OE algorithms

Ecoffet, Clune, Lehman 2020, Open Questions in Creating Safe Open-

• We must proceed cautiously and wisely, and prioritize safety



# A Paradox

 If you try too hard to solve a hard problem, you'll fail If you ignore the objective, you're more likely to succeed



Maximize Reward: Fails Maximize Novelty: Succeeds Novelty Search: Lehman & Stanley

# Key for Science & Technological Innovation: Generating Problems, Goal Switching











Conjecture: The only way to solve hard problems may be by creating problems while you solve them and goal switching between them



## When trying to solve task A, if you make progress on task B also start optimizing for B







## We want our algorithms to capture serendipitous discoveries

## "Goal Switching" Nguyen, Yosinski & Clune 2016



# Quality Diversity Algorithms

 a diverse set of high-performing agents (policies)



- Multi-dimensional archive of phenotypic elites
  - Choose dimensions of interest in behavior space
  - Discretize
  - Perturb, locate, replace if better, repeat





- Multi-dimensional archive of phenotypic elites
  - Choose dimensions of interest in behavior space
  - Discretize
  - Perturb, locate, replace if better, repeat

## random evaluate agent







0.6

0.4

- Multi-dimensional archive of phenotypic elites
  - Choose dimensions of interest in behavior space
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## random evaluate agent





0.8

0.6

0.4

- Multi-dimensional archive of phenotypic elites
  - Choose dimensions of interest in behavior space
  - Discretize  $\bullet$





0.6

0.4

- Multi-dimensional archive of phenotypic elites
  - Choose dimensions of interest in behavior space
  - Discretize ightarrow





0.6

0.4

# Multi-dimen

- Choose dim ullet
- Discretize ightarrow
- Perturb, loca



## Set of diverse, high-quality solutions





# of phenotypic elites est in behavior space

# tter, repeat Height Weight



# Soft Robots Problem

Mouret & Clune 2015, arXiv

## Dimensions

- number of voxels
- % bone (dark blue)



Cheney, MacCurdy, Clune, Lipson 2014



## Qualitatively Different Mouret & Clune 2015, arXiv

## Classic Optimization



## soft robots problem

## Classic + Diversity

## **MAP-Elites**

same # evals!

## Often finds a better max than max-focused algorithms

50	
45	
40	
35	
30	
25	
20	
15	
10	
05	
00	

# Goal Switching is Critical



# Lineage of a Final Solution

circle = iteration 0, color = reward



THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

## Backonits feet Using an intelligent trial-and-error learning algorithm this robot adapts to injury in minutes

PAGES 426 & 503

# Robots that adapt like animals 2015

## Produces rapid adaptation



# Go-Explore A new approach for hard-exploration problems



Adrien Ecoffet



Joost Huizinga



Joel Lehman



Ken Stanley



Jeff Clune

## Nature 2021



# Grand Challenge in RL: Effective Exploration

- Hard-exploration problems
  - Sparse-rewards
    - rare feedback
    - Montezuma's Revenge
      - Was a (mini) grand challenge



# Results on Montezuma's Revenge



- Avg: 660,000+ points
- Best:
  - scores ~18 million
  - solved 1,141 levels
- Beats human world record ~1.2 million



# Solved all Atari games



# Simulated Hard-Exploration Robotics Task



## Target: Top LeftTarget: Top Right





PPO+Intrinsic Motivation fails due to derailment

# What's missing?

- QD algorithms
  - a diverse set of high-performing agents (policies)
  - exploration and goal-switching
- But they're stuck in a single environment

## **MAP-Elites**



50	
45	
40	
35	
30	
25	
20	
15	
10	
05	
00	

# Traditional ML

## We pick challenges and solve them





## Starcraft







## Dota 2

# **Open-Ended Algorithms**

- Endlessly innovate
- Examples
  - Natural evolution
  - Human culture (science, technology, art)
- Can we make algorithms that do this?
  - Worth running for a billion years?









# Intriguing Possibility

- Could the algorithm generate its own challenges and solve them?
  - niche/challenge/opportunity/problem:
    - tree leaves
  - solution:
    - giraffes
    - caterpillars









# Paired Open-Ended Trailblazer (POET)



Rui Wang



Joel Lehman

\*Co-senior authors

## Endlessly Generating Increasingly Complex and **Diverse Learning Environments and their Solutions**



Jeff Clune\*



Ken Stanley\*

GECCO 2019



- Encode environments
- Periodically
  - Generate new learning environments
    - add to population IF
      - not too easy, not too hard
      - novel
- Optimize agents to solve each one
  - allow goal-switching

# POET











# **Direct Optimization Fails**



# Hand-Designed Curricula Fail Too (see paper)

Enhanced POET. R Wang, J Lehman, A Rawal, J Zhi, Y Li, J Clune, K Stanley (2020) ICML

# **Producing all this** diversity (and more) in a single run

Enhanced POET. R Wang, J Lehman, A Rawal, J Zhi, Y Li, J Clune, K Stanley (2020) ICML

—

# **POET-Inspired Work Outdoors** Joonho et al. Science Robotics. 2020



# **POET: Conclusions**

- Shows benefits of
  - QD
  - generating challenges while solving them



- Pro: auto-generates tasks

# Con: small, hand-chosen distribution of environments/tasks
## Artificial General Intelligence (AGI) or Human-level AI, if you prefer

## If we should make it

• We have a long way to go

• How will we get there?



## Clear Machine Learning Trend: Hand-designed pipelines are ultimately outperformed by learned solutions

## hand designed ----> learned

- Features
- Architectures
- Hyperparameters & data augmentation
- RL algorithms



suggests alternate path



## Al-Generating Algorithms Clune 2019

- Lots of pre-training
  - produces a sample-efficient, intelligent agent
- Existence proof
  - Earth



## Al-Generating Algorithms Clune 2019

## Three Pillars

- 1. Meta-learn architectures
- 2. Meta-learn learning algorithms
- 3. Generate effective learning environments

Handcrafting each is slow, limited by our intelligence/time Better to learn them. Let ML+compute do the heavy lifting



## Al-Generating Algorithms Clune 2019

## Three Pillars

- 1. Meta-learn architectures
- 2. Meta-learn learning algorithms
- 3. Generate effective learning environments
  - Quality Diversity algorithms ٠
  - **Open-Ended algorithms**  $\bullet$
  - e.g. POET



- Motivate QD, open-ended and Al-generating algorithms
- Discuss new possibilities unlocked by "foundation models"



- Motivate QD, open-ended and Al-generating algorithms
- Discuss new possibilities unlocked by "foundation models"



## OMNI **Open-endedness via Models of human Notions of Interestingness**





### Jenny Zhang\*

### Joel Lehman Ken Stanley



### Jeff Clune\*

### UBC, Vector Institute

# To Produce Open-Ended Algorithms / Al-GAs

• We need a vast task/environment space



# All Tasks Described by Words



## Many tasks: impossible, nonsense, too hard, or too easy





# Tasks Must be New & Interesting

# How do we find them?

# First Challenge: Tasks Must Have Learning Progress Filters out impossible, too hard, and too easy tasks e.g. POET



### POET Wang et al. 2019; Enhanced POET Wang et al. 2020

# Problem

- new
  - 3.14
  - 3.14159265358979323
  - 3.141592653589793238462643383279502884197
- Needed: way to automatically determine what is learnable and interestingly new

## Easy to have learning progress without being interestingly

# **Problem: Quantifying Interestingness**

- Goodhart's law



Find new states = noisy TV problem

 Hand-coded new/interesting/novelty metrics produce pathologies • "When a measure becomes a target, it ceases to be a good measure"



Do new movements = endless twitching



# Problem: Quantifying Interestingness

- Past approaches (hand coding) do not work
  - We cannot define it, but we know it when we see it - Justice Stewart, paraphrased
- Automatically identifying interestingness is the most important problem in open-endedness



# An answer! **Foundation Models**

- FMs already know what is interesting
  - They have read the entire Internet
  - Including LOTs of humans talking about what is interesting vs. not
  - Have common sense
- Insight: we can just ask them!



## Open-endedness via Models of human Notions of Interestingness



- Reinforcement Learning, Task-conditioned
- Task sampler
  - High learning progress
  - Are interesting





Learning Progress Which tasks are learnable?

+

sampler

Task

**Model of Interestingness** Which tasks are interesting?

## Sample tasks with higher learning progress Using Kanitscheider et al. 2021



<sup>1</sup> Kanitscheider, Ingmar, et al. "Multi-task curriculum learning in a complex, visual, hard-exploration domain: Minecraft." arXiv preprint arXiv:2106.14876 (2021).



uniform, no exploration bonus uniform, fixed exploration bonus \_ \_ \_ uniform, dynamic exploration bonus \_\_\_\_ bidirectional learning progress curriculum .... unidirectional learning progress curriculum

sampler Task

Learning Progress Which tasks are learnable?

+

**Model of Interestingness** Which tasks are interesting?

# Model of Interestingness (Mol)

• GPT

### Goals

The ultimate goal that [the agent] would like your help with is to learn as many interestingly different skills as possible ...

### **Environment description**

The grid world has objects in six distinct colors ... Each task is a sequence of instructions ...

### Tasks the agent currently does well:

"open some door", "go to some object"

### **Predict which of these tasks are interesting:** "pick up some object", "open some door, then go to some object"



## Crafter



## BabyAl



# Results



### Results on a Human-Predefined Set of Interesting Tasks



- More complex domain
  Kitchen env (Thor)
- Any task specifiable in natural language
- Challenge: requires a "universal reward function"
  - says if any task has been completed



# Solution: ask GPT for reward function code

- Prompt
  - Generate the next new, interesting, learnable tasks
  - and code to check if each is done

### Next tasks

1. Pick up the knife. 2....

### Code to check if the task is completed

2 . ...

1. [[obj\_attributes("Knife", "visible": True)], [obj\_attributes("Knife", "isPickedUp": True)]]













- Pro: infinite task space
- Con: still one type of environment

- - Can express any environment

# OMNI

• Needed: Darwin Complete environmental search space (Clune 2019)



# Darwin Complete Clune 2019, Al-Generating Algorithms

- A search space that can express any environment
- So far, I've only thought of two 1. Code!





## Open-endedness via Models of human Notions of Interestingness via Environments Programmed In Code





Jenny Zhang

### Maxence Faldor Antoine Cully

# CINIE E PIC

Jeff Clune

# Idea

- Is thus Darwin Complete!

## Have OMNI produce code for new environments and reward functions

### Seed 1

### Cross a pride-colored bridge with gaps to reach a platform





# Cross a bridge with moving segments to reach a platform





# Kick a ball into a goal with obstacles





### Cross a rainbow bridge with moving segments and gaps to reach a platform





# Navigate a dynamic obstacle course to reach a target


# Navigate a terrain with obstacles to reach a target zone

success detector: false human review: fail



## Touch a lever or a button to activate a drawbridge

success detector: true human review: success





## Push a domino to start a chain reaction

success detector: true human review: success



## Task: Destroy a tower of blocks

success detector: true human review: success















## **OMNI: Conclusion and Future Work**

- OMNI: Open-endedness via Models of human Notions of Interestingness
- Finally (!!) enables us to focus on interesting tasks
  - FMs have learned that ineffable concept from humans!
- OMNI-EPIC: generate any possible environment
- Excited to scale OMNI and see its creativity: billions of years?





### **Darwin Complete** Clune 2019, Al-Generating Algorithms

- Can express any environment
- So far, I've only thought of two
  - Original Paper: Deep Neural Network
  - Recently: Code! (OMNI-EPIC)





### **Genie: Generative Interactive Environments**

Jake Bruce\*, Michael Dennis\*, Ashley Edwards\*, Jack Parker-Holder\*, Yuge (Jimmy) Shi\*, Edward Hughes, Matthew Lai, Aditi Mavalankar, Richie Steigerwald, Chris Apps, Yusuf Aytar, Sarah Bechtle, Feryal Behbahani, Stephanie Chan, Nicolas Heess, Lucy Gonzalez, Simon Osindero, Sherjil Ozair, Scott Reed, Jingwei Zhang, Konrad Zolna, Jeff Clune, Nando de Freitas, Satinder Singh, Tim Rocktäschel\*

- A world model that can generate any environment (a video game)
  - conditioned on any of the following: text, image, sketch, etc.
- Trained from online videos











### Genie: Generative Interactive Environments Generate any environment via text, image, sketch, etc. From Online Videos with No Labels

#### Generate a playable world set in a futuristic city

Jake Bruce\*, Michael Dennis\*, Ashley Edwards\*, Jack Parker-Holder\*, Yuge (Jimmy) Shi\*, Edward Hughes, Matthew Lai, Aditi Mavalankar, Richie Steigerwald, Chris Apps, Yusuf Aytar, Sarah Bechtle, Feryal Behbahani, Stephanie Chan, Nicolas Heess, Lucy Gonzalez, Simon Osindero, Sherjil Ozair, Scott Reed, Jingwei Zhang, Konrad Zolna, Jeff Clune, Nando de Freitas, Satinder Singh, Tim Rocktäschel\*







https://sites.google.com/view/genie-2024

#### **Results from Genie 1**



### Scaling Laws: More compute = better

### Genie: Generative Interactive Environments



### Video Games, by Seneca and Caspian Clune (Ages 7 and 9)





### Genie: Generative Interactive Environments



#### Can generate robotics training environments too



https://sites.google.com/view/genie-2024





## Foundation World Model

- Genie can be considered a "foundation world model"
- Lots of analogies to Foundation Models
  - General: can generate any environment
  - Foundational: Lots can be build upon it
  - Similar methods apply
    - It can be fine-tuned
    - RLHFed, etc.
- Scaling laws apply
- Etc.

### Genie 2: A large-scale foundation world model

### Generate a playable world on a spaceship

https://deepmind.google/discover/blog/genie-2-a-large-scale-foundation-world-model

#### Go through the left door





#### Go through the center door



#### Go through the right door



















## Imagine

- Open-ended algorithms + Genie
  - Including Genie 3, 4, 5...10
- Incredibly exciting and powerful
- "Genie 2 could enable future agents to be trained and evaluated in a limitless curriculum of novel worlds" - Parker-Holder et al. 2024

### Al-Generating Algorithms Clune 2019

### Three Pillars

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- 3. Generate effective learning environments
  - Quality Diversity algorithms ٠
  - **Open-Ended algorithms**  $\bullet$ 
    - e.g. POET, OMNI, OMNI-EPIC
  - Foundation World Models
    - e.g. Genie



### Al-Generating Algorithms Clune 2019

### Three Pillars

1. Meta-learn architectures

### 2. Meta-learn learning algorithms

- 3. Generate effective learning environments
  - Quality Diversity algorithms
  - Open-Ended algorithms
    - Eg. POET, OMNI, OMNI-EPIC
  - Foundation World Models



## Video Pre-Training (VPT)

#### Video PreTraining (VPT): Learning to Act by Watching Unlabeled Online Videos

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Adrien Ecoffet\*† Brandon Houghton\*† adrien@openai.com brandon@openai.com

> Jeff Clune<sup>\*†‡</sup> jclune@gmail.com





Joost Huizinga\*† joost@openai.com

Raul Sampedro\*† raulsamg@gmail.com

### NeurIPS 2022

### 

### Hard Exploration Prevents Open-Ended Learning

- RL often fails to learn because exploration is too hard
- Prevents open-ended algorithms
- In theory, meta-learning from scratch can address this, but it might take forever





# Can we make AI-GAs without a planet-sized computer?

### Yes

(to borrow from Newton) Al sees further by standing on the shoulders of giant<del>s</del> human datasets



### Solution? Internet videos/tutorials









### Challenge

### Videos are unlabeled

- online data
  - text: next word
  - music: next note
  - images: next pixel
- we need actions taken at each timestep





Actions

### unlike text, music, and images, you do not get labels "for free" in

### Learns to predict action taken based on past and future



#### Easy Problem: Which action was taken?

### Train "Inverse Dynamics Model"





### Label Online Videos



Video Frames



Actions



### Imitation Learning / Behavioral Cloning





~8 years (70,000 hours)



recent video frames → action Transformer w ~ 500M params

## Pretraining (zero shot)



Pre-train on X hours, then fine-tune on Early Game

Stone Tools Human: ~139s (2780 Actions)



### Pre-Training Produces Intelligent Behavior, Including Exploration



Crafting a stone pickaxe

Constructing a rudimentary wooden shelter

Searching through a village

## Fine Tuning with RL

### Task: Create Diamond Pickaxe



#### Reward (Roughly)

## Fine Tuning with RL





**Diamond Tools** Human: ~20min (24,000 Actions)

#### tldr; pretraining enables RL to learn hard-exploration tasks



#### Spawns next to tree and starts chopping

2.5x Speed Total of 0:15 Minutes (~300 Actions)







Continues to dig, now with a stone pickaxe. Finds a cave!

MineRLAgent0 has made the advancement [Getting an Upgrade]

3x Speed Total of 0:57 Minutes (~1.1k Actions)







## **VPT Conclusions**

- Should greatly catalyze open-ended algorithms



# Pre-training enables learning hard-exploration tasks efficiently

### More on VPT

- Blog:
  - https://openai.com/research/vpt
- Entire talk on VPT:
  - https://youtu.be/XQco1A6-RNI?t=13033
- Paper
  - https://arxiv.org/abs/2206.11795


# SIMA

## • One agent, language-conditional, in many different environments















See blog for author list: https://deepmind.google/discover/blog/sima-generalist-ai-agent-for-3d-virtual-environments

specialized agent

### Go through the left door





### Go through the center door



### Go through the right door

## SIMA off the shelf!



# VPT & SIMA Conclusions

- Should greatly catalyze open-ended algorithms

## More on VPT

- Blog:
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- Entire talk on VPT:
  - https://youtu.be/XQco1A6-RNI?t=13033
- Paper
  - https://arxiv.org/abs/2206.11795

Pre-training enables learning hard-exploration tasks efficiently

### More on SIMA

- Blog:
  - https://deepmind.google/discover/blog/ <u>sima-generalist-ai-agent-for-3d-virtual-</u> environments/
- Paper
  - https://arxiv.org/abs/2404.10179



# Automated Design of Agentic Systems





### Shengran Hu





### Cong Lu

### Jeff Clune

# LLMs —> "Agentic Systems"









## Agentic System



## Designing agents requires a significant amount of manual effort



Partial list of existing building blocks, applications, agent designs, etc. (Xi et al., 2023)



# Automatic Design of Agentic Systems (ADAS)

- AI-GA philosophy
  - Have AI create agentic systems
- Open-ended core ideas
  - Growing archive of stepping stones
    - **High-quality**
    - Interestingly diverse (via OMNI) ightarrow
- We're not the first
  - prompt optimization: OPRO, Yang et al. 2024
  - graph search space: GPTSwarm, Zhuge et al. 2024







- Define agentic systems in code (python)
  - A first
- Turing Complete: can create any agentic system If interesting and/or good, add to archive
- A meta-agent creates each new agent

# Meta-Agent Search



## Repeat

- Look at archive, create new variant
- If interesting and/or good, add to archive



# Meta-Agent Search

### Next interesting agent

**New Agent** 

Summary and motivation: "Based on the insights from previous agents ...", Name: "Divide and Conquer Agent", Code: "def forward(Task):

return Answer"

.....

Test performance on tasks

and add to archive

# Meta Agent Search

The Meta Agent







### Refine until novel and error-free

## Next Interesting Agent

The Meta Agent

 $\odot \odot$ 



# ARC challenge

## Meta Agent Search outperform SOTA hand-designed agents



## **Reasoning and Problem-Solving Domains** Meta Agent Search outperform SOTA hand-designed agents



Best Agents from Meta Agent Search

F1 Score	Accuracy (%)				
ng Comprehension	Math Multi-task		Science		
: Han 1-designed Agents					
54.2 ± 0.9	$28.0 \pm 3.1$	$5.4 \pm 3.3$	2.9.2 ± 3.1		
$64.4 \pm 0.8$	$28.2\pm3.1$	$\textbf{65.9} \pm \textbf{3.2}$	$30.5 \pm 3.2$		
$59.2 \pm 0.9$	$27.5 \pm 3.1$	$63.5 \pm 3.4$	$\textbf{31.6} \pm \textbf{3.2}$		
$60.6 \pm 0.9$	$\textbf{39.0} \pm \textbf{3.4}$	$65.6 \pm 3.3$	$31.4 \pm 3.2$		
$60.4 \pm 1.0$	$31.1 \pm 3.2$	$65.1 \pm 3.3$	$26.9\pm3.0$		
$61.8 \pm 0.9$	$23.8\pm3.0$	$65.1 \pm 3.3$	$30.2 \pm 3.1$		
$65.8 \pm 0.9$	$30.1 \pm 3.2$	$64.5 \pm 3.3$	$31.1 \pm 3.1$		
ntic Systems on Different Domains					
$79.4 \pm 0.8$	$\textbf{53.4} \pm \textbf{3.5}$	69.6 ± 3.2	<b>34.6 ± 3.2</b>		

### Transferability and Generalizability Non-math domains Transfer to Math and Non-Math Domains Math domains

Agent Name		Accurac (%)			<b>1</b> Score
	MGSM	GSM8K	<b>GSM-Hard</b>	MMLU	DROP
Mar ally Designed Agents					
Chain-of-Thought (Wei et al., 2022)	$28.0\pm3.1$	$34.9\pm3.2$	$15.0\pm2.5$	$65.4 \pm 3.3$	$64.2\pm0.9$
COT-SC (Wang et al., 2023b)	$28.2\pm3.1$	$37.8\pm3.4$	$15.5\pm2.5$	$65.9 \pm 3.2$	$64.4\pm0.8$
Self-Refine (Madaan et al., 2024)	$27.5\pm3.1$	$38.9\pm3.4$	$15.1\pm2.4$	$63.5\pm3.4$	$59.2\pm0.9$
LLM Debate (Du et al., 2023)	$39.0 \pm 3.4$	$43.6 \pm 3.4$	$17.4\pm2.6$	$65.6\pm3.3$	$60.6\pm0.9$
Step-back Abstraction (Zheng et al., 2023)	$31.1\pm3.2$	$31.5\pm3.3$	$12.2\pm2.3$	$65.1\pm3.3$	$60.4 \pm 1.0$
Quality-Diversity (Lu et al., 2024c)	$23.8\pm3.0$	$28.0\pm3.1$	$14.1\pm2.4$	$65.1\pm3.1$	$61.8\pm0.9$
Role Assignment (Xu et al., 2023)	$30.1\pm3.2$	$37.0\pm3.4$	$18.0 \pm 2.7$	$64.5\pm3.3$	$65.8 \pm 0.9$
Top Agents Searched on MGSM (M	lath)	Transferr Math D	ed within Oomains	Transferre Math D	ed beyond omains
Dynamic Role-Playing Architecture	$53.4 \pm 3.5$	$69.5 \pm 3.2$	$31.2 \pm 3.2$	$62.4 \pm 3.4$	$70.4\pm0.9$
Structured Multimodal Feedback Loop	$50.2\pm3.5$	$64.5\pm3.4$	$30.1\pm3.2$	$67.0 \pm 3.2$	$70.4\pm0.9$
Interactive Multimodal Feedback Loop	$47.4\pm3.5$	$64.9\pm3.3$	$27.6\pm3.2$	$64.8\pm3.3$	$71.9 \pm 0.8$

Agent Name	Accurac (%)			1 Score	
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Top Agents Searched on MGSM (Math)		Transferred within Math Domains		Transferred beyond Math Domains	
Dynamic Role-Playing Architecture	$53.4 \pm 3.5$	$69.5 \pm 3.2$	$31.2 \pm 3.2$	$62.4 \pm 3.4$	$70.4\pm0.9$
Structured Multimodal Feedback Loop	$50.2\pm3.5$	$64.5\pm3.4$	$30.1\pm3.2$	$67.0 \pm 3.2$	$70.4\pm0.9$
Interactive Multimodal Feedback Loop	$47.4\pm3.5$	$64.9\pm3.3$	$27.6\pm3.2$	$64.8 \pm 3.3$	$71.9 \pm 0.8$



- We followed community best practices for safety
  - containerization
  - monitoring
    - we did not observe dangerous behaviors of agents
- More work is needed though
  - e.g. infusing constitutional Al
- Exciting & important future work on safety in ADAS and all self-improving Al



## Future work

## • Higher-order ADAS

- The meta agent can be also improved by ADAS!
- All code, prompts, & generated agents are open source



# **ADAS Conclusion**

- Automated Design of Agentic Systems
  - From hand-crafted to learned agents
  - Automated & higher-performing
- Meta Agent Search:
  - 1st ADAS in code space
  - Discovers high-performing, transferable agents

## The AI Scientist **Towards Fully Automated Open-Ended Scientific Discovery**



Chris Lu\*







### Jakob Foerster<sup>†</sup>



Cong Lu\*



### Robert Lange\*



### Jeff Clune<sup>†</sup>

David Ha<sup>†</sup>

# The Al Scientist

- Science is the ultimate open-ended domain
- Can Al automate all of science?
- Yes!

## n-ended domain nce?

# Domain

- We chose ML
  - The computer IS the "real world"
- Could be applied to other domains
  - With simulators and or automated labs



'ld" omains ated labs

# The Al Scientist

- Generates ideas
- Designs and runs experiments
- Analyzes and visualizes results
- Writes entire scientific manuscript
- Conducts peer review
- Adds "published" papers to archive
- Repeat to build on discoveries

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## An Automated Reviewing Agent: Results on ICLR 2022 Benchmark



### The AI Scientist: Write-Up - 2D Diffusion

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DUALSCALE DIFFUSION: ADAPTINE FEATURE BAL-ANCING FOR LOW-DIMENSIONAL GENERATIVE MOD-ELS.

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### 1 INTRODUCTION

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### 2.2 ADDITIONNEH AND PROPERTY MEDICE

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buy dimensional viettings. Themis performance important in our providing output the matters, requestions of general and head beamers are trace suggestionably around different density, and demaning	$\partial (\mathbf{x}   \mathbf{x}_{i+1}) \otimes \mathcal{N}(\mathbf{x}_{i}   \sqrt{1 - \delta} \mathbf{x}_{i}) \otimes \mathcal{M}_{i}$ (1)	WELL-SHERRY MURICIPAL
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<ul> <li>Environmentation descriptions and the based of Selection and data sector many.</li> </ul>	the material branch from states of a material strategies of	na wate MLD, is can be card as
Institute generationet et appendig unite distata es con determinant aporte, antecerren santation et al. (2002) desente ested for effectivation of effectivation models is capturing complexity productions in a	$\mu(\mathbf{x}_{i+1} \mathbf{x}) = \omega^2(\mathbf{x}_{i+1} \mathbf{x}) \cdot \nabla \mathbf{x}_i(\mathbf{x}_i, t) + (2i)$ (4) Then form build represent the formulation of the state of	<pre>MEF_())= Among Care(Mod.) (Among (Among (Among (A))))</pre>
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queet. Our molecule dynamic half acting of godini and local Sumara sets in upon from their math- near operation are taken a providence action on opporing comparts are categorised as comparisons.	distribute for Senaltandre Indiversity section.	boly should reactive and local details a to-predictions with the balance dynamically also particle current structure
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Diffusion models have energipt as a posterin class of presentive models, achieving remarkable	About 5, we prote a new an interact discharge and space and space in interactiveness point and tool. For any designed the design of process.	$\mathcal{L} \in [0, \infty)$ [ $b = \min[10^4]$ ]
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apparticular by	2 <sup>64</sup> or the ABR Line of the Option	<ol> <li>Comparison complexity, using the forward process defined in Science 3, 5, Complements and Lance speak the mouse parameters and gradient decimet.</li> </ol>
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# Results

![](_page_131_Figure_1.jpeg)

Mostly 3-5: reject to borderline Some: 5s and 6s (weak accepts!)

![](_page_131_Picture_3.jpeg)

![](_page_132_Picture_0.jpeg)

NO WAY! This is nearly EXACTLY one of the paper ideas The AI Scientist came up with! It was one of my favorite ideas it generated, and made us very impressed with its creativity and good taste in a proposal for an ML paper. Cool to see humans agree! The humans def executed better though. See The AI Scientist appendix for the AI-generated version: x.com/jeffclune/stat...

AI-Scientist Generated Preprint

### GROKKING THROUGH COMPRESSION: UNVEILING SUDDEN GENERALIZATION VIA MINIMAL DESCRIP-TION LENGTH

Anonymous authors Paper under double-blind review

This paper investigates the relationship between Minimal Description Length (MDL) and the phenomenon of grokking in neural networks, offering an information-theoretic perspective on sudden generalization. Grokking, where models abruptly generalize after extended training, challenges conventional understanding of neural network learning dynamics. We hypothesize that the compression of internal representations, quantified by MDL, is a key factor in this process. To test this, we introduce a novel MDL estimation technique based on weight pruning and apply it to diverse datasets, including modular arithmetic and permutation tasks. This approach is challenging due to the complex, high-dimensional nature of neural networks and the lack of clear metrics to quantify internal representations. Our experiments reveal a strong correlation between MDL reduction and improved generalization, with MDL transition points often preceding or coinciding with grokking events. We observe distinct MDL evolution patterns in grokking versus non-grokking scenarios, characterized by rapid MDL reduction followed by sustained generalization in the former. These findings provide insights into the

### ×1 …

### ABSTRACT

- More general (broader topic areas)
- Better search (agentic tree search)
- Multi-modal (agent can see with vision-language model)
- Generated paper accepted via peer-review!
  - Workshop at ICLR

# V2

- Containerization
- Watermarking
  - Full transparency always
- More work needed
  - not exploring dangerous areas
  - refusing requests to do unethical science
- Impact on publishing ecosystem?

![](_page_134_Picture_8.jpeg)

# **Conclusions: The Al Scientist**

- The entire process can be automated
- Far from perfectly though
  - For now

![](_page_135_Picture_6.jpeg)

- So much!
  - Scale
  - Different domains
  - Better models
  - It building on its own discoveries
- Everything is open source
  - github.com/SakanaAl/Al-Scientist

# Future Work: The Al Scientist

![](_page_136_Picture_11.jpeg)

![](_page_136_Picture_12.jpeg)

## Thought Cloning Learning to Think while Acting by Imitating Human Thinking

![](_page_137_Picture_1.jpeg)

### Shengran Hu

![](_page_137_Picture_3.jpeg)

### Jeff Clune

# Language

- But AI agents rarely think in natural language
- Thinking agents might learn, perform, and generalize better

![](_page_138_Figure_3.jpeg)

## tural language erform, and generalize better

# Thought Cloning

Imitate humans thinking out loud while they act • Teaches AI how to think while acting

# **Behavioral Cloning**

![](_page_140_Figure_1.jpeg)

# Thought Cloning

![](_page_141_Figure_1.jpeg)

# Thought Cloning: Faster Learning, Better Performance

![](_page_142_Figure_1.jpeg)

![](_page_142_Picture_2.jpeg)

# Generalizes and adapts better to out-of-distribution environments

![](_page_143_Figure_1.jpeg)
## TC Agents are Interpretable

- You can watch them think
- Makes debugging/ improving them easier



I can't open the door Because a person is there

## TC Agents are Interpretable

- You can watch them think
- Makes debugging/ improving them easier
- Improves safety
  - You understand the agent more before deciding to deploy

Open the door, even if a child is in the way

### Precrime Prevention: A simple, effective method to enhance AI Safety



# Watch thoughts, stop if agent plans to do something bad

### MINORITY REPORT

Next, I'll rob a bank





### **Precrime Prevention:** A simple, effective method to enhance Al Safety



Unsafe Behaviors

### Overall Conclusions 1/3

Quality Diversity Algorithms

- Explore well
- Create & collect stepping stones
- Harness goal switching
- Invent effective, counterintuitive curricula
- **Open-Ended Algorithms** 
  - Goal: create algorithms that *endlessly* learn & innovate
    - Like natural evolution and human culture
- Al-Generating Algorithms
  - Open-endedness to produce AGI
  - Likely to be fastest path to Al















## **Overall Conclusions 2/3**

- Open-endedness and AI-GAs are the next wave in AI Via Foundation Models, OE algorithms can stand on the shoulders of giant human datasets
- - Great catalysts
  - Both
    - Environments (Genie)
    - Agents (VPT, Sima)
      - Evolution took 3.5 billion years to produce humans ightarrow
      - VPT/Sima allow us to leapfrog to the interesting part ightarrow



## Overall Conclusions 3/3

- OMNI-EPIC: we can finally pursue what is interesting!
  - In Darwin Complete search spaces
  - Avoids the pitfall of trying to define "interesting"
  - Profound opportunities for QD,OE, AI-GAs, etc.
- The AI Scientist
  - Same set of exciting ideas applied to agents and science itself!
- + Thought Cloning
  - Adds performance, generalization, adaptability
  - Also interpretability, debugability, and safety

### Main collaborators

- Jenny Zhang
- Joel Lehman
- Ken Stanley
- Maxence Faldor
- Antoine Cully
- Shengran Hu
- Cong Lu
- VPT Team @ OpenAl
- Genie & SIMA teams @ DeepMind
- Al Scientist team

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