

LLMs are more Memory than Mystery

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Abstract

This paper presents the design and implementation of two approaches to solve the Abstraction & Reasoning Corpus (ARC), a few-shot benchmark of human-level abstract problem-solving, to serve as a north-star towards Artificial General Intelligence (AGI). The first approach features a neuro-symbolic reasoning system using LLMs, while the second approach uses brute-force technique like Genetic Algorithm (GA) combined with Domain-Specific Language (DSL) to tackle ARC. Our first approach proposes a modular pipeline that (1) encodes colored grid tasks into a compact 64-token representation, (2) enriches training data with Re-ARC and Concept-ARC augmentations, (3) fine-tunes decoder-only language models (e.g., LLaMA-3.2B, NeMo-Minitron-8B) via Low-Rank Adaptation (LoRA) under tight compute budgets, and (4) applies a depth-first-search sampler with log-softmax scoring to yield and rank candidate solutions across multiple augmented views. Compared to classical and prior neural approaches, achieves a better output through pipeline integration of LLM & continuous Augmentation. Our open-source toolkit not only demonstrates latent abstract reasoning capabilities in large language models but also introduces a reusable DSL for grid transformations and a data-centric augmentation suite. Our second approach, utilizing DSL+GA, provides structured guidance through the search space. We describe the DSL primitives and GA design in detail and analyse the code structure. We then compare state-of-art systems on ARC. This work lays a foundation for AGI research and paves the way for future extensions in few-shot generalization, program synthesis, and cognitive-inspired AI.

Introduction

Artificial General Intelligence (AGI), a form of intelligence that matches or exceeds human intellectual capabilities across a broad range of cognitive tasks, remains the holy grail of AI research. Unlike narrow AI - designed to excel at a specific task - AGI requires adaptable, flexible reasoning and learning abilities. As François Chollet - founder of Keras deep-learning library - rightly observes, current benchmarks often measure skill in fixed domains, achievable by “buying” performance with massive data and compute, rather than truly assessing generalization or creativity [1]. Consequently, defining and evaluating genuine intelligence demands new frameworks - ones that reward rapid skill acquisition and strong reasoning over isolated expertise.

In response, Chollet introduced the **Abstraction and Reasoning Corpus (ARC)** in his seminal 2019 paper “*On the Measure of Intelligence*” [1]. ARC is a collection of deliberately designed visual reasoning tasks inspired by human cognitive priors, such as object permanence, geometry, number sense, and goal-directed behavior - even without cultural or language-specific cues [2]. Instead of using vast training data, each ARC task offers only a few input-output examples (typically around three), challenging solvers - whether human or machine - to deduce the underlying transformation rule and apply it to new test cases [2].

ARC stands out as a benchmark of AGI because it shifts the focus from “skill performance” to skill-acquisition efficiency: how swiftly and flexibly one can learn new abstract reasoning skills from minimal examples [1]. Chollet provides a formal definition of intelligence rooted in Algorithmic Information Theory, linking it to an agent’s capacity to generalize from sparse data in novel situations [1]. ARC operationalizes this definition by offering around 800 core tasks (400 for training, 400 for public evaluation, plus additional held-out sets), each crafted to resist brute-force solutions and emphasize abstraction over memorization [3].

Chollet’s choice to align ARC’s tasks with nearly innate human priors (e.g., identifying objects, counting, understanding spatial relations) enables meaningful comparisons between machine and human performance [1]. Humans routinely solve over 86% of the tasks with ease, reflecting the benchmark’s design as a test of general intelligence, rather than domain-specific expertise [4]. By contrast, traditional deep learning models and even advanced large language models (LLMs) published before 2025 barely scrape past zero - further highlighting the gulf between human and machine reasoning [4].

ARC was first introduced in 2019, coinciding with Chollet’s critique of narrow-AI benchmarks and his proposal for a general intelligence metric [1]. The ongoing evolution of ARC reinforces its role as a dynamic **benchmark for AGI**, with increasingly complex tasks calibrated to human baseline performance [7]. Its continued refinement ensures it remains a critical test for algorithms that aspire to human-like adaptability and abstract reasoning.

Abstraction and Reasoning Corpus (ARC)

The Abstraction and Reasoning Corpus (ARC), created before LLMs even existed, is not merely a collection of puzzles - it is a meticulously designed dataset crafted to simulate the challenges of

human-like abstraction and analogical reasoning. Introduced by François Chollet in 2019, the dataset comprises hundreds of small grid-based tasks, each consisting of a few input-output examples. These examples are meant to allow a human or an intelligent agent to infer the underlying transformation logic and apply it to new, unseen test inputs [1].

Each ARC task is structured as a collection of colored 2D grids, where each cell in the grid can hold a color value represented by an integer. A task typically includes three to five training pairs (input and expected output) and one or more test inputs for which the agent must generate the correct output [2]. These grids may vary in size, typically between 3×3 and 30×30 , and the tasks are intentionally free from textual, numeric, or symbolic labels, emphasizing purely visual and structural understanding.

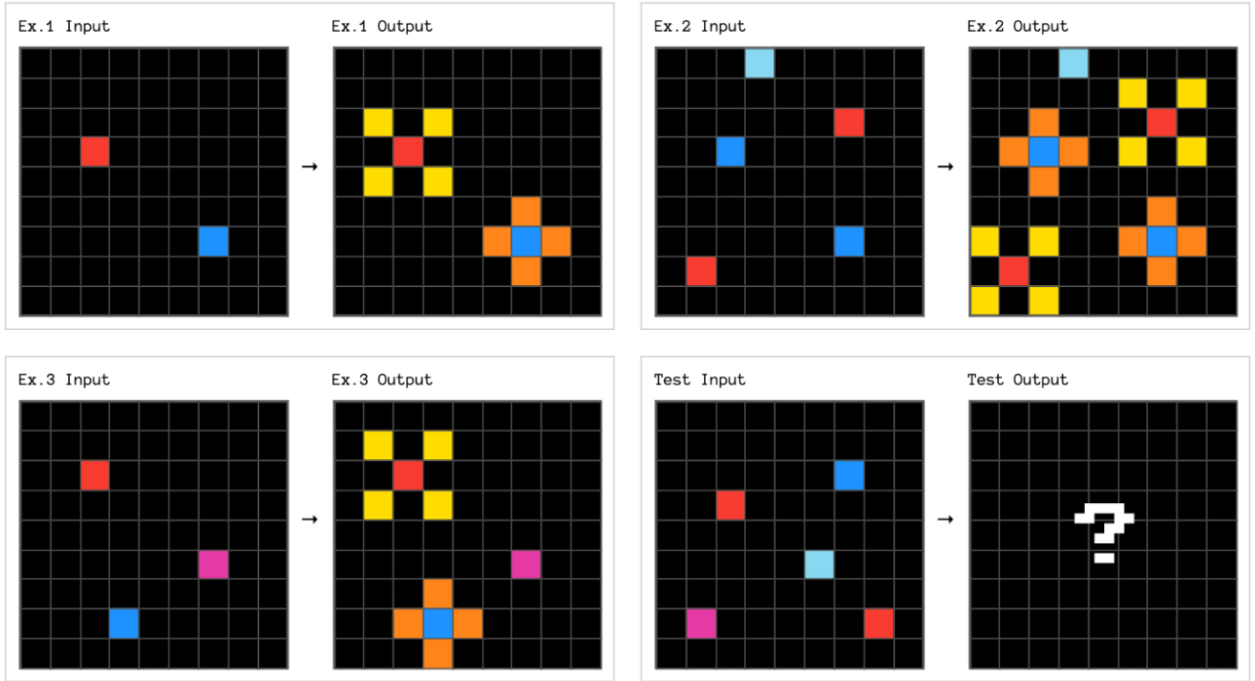


Figure 1: Examples of ARC-AGI tasks

What distinguishes ARC from traditional supervised learning datasets is that it does not support generalization through statistical learning. Instead, ARC tasks are designed to be solved from scratch, each requiring fresh reasoning with no benefit from training across tasks. This eliminates any advantage from pre-training on large corpora or memorizing task patterns. Each task in ARC is treated as an isolated reasoning problem, mimicking how a human would encounter and solve a logic puzzle for the first time [1], [7].

Chollet categorized the cognitive abilities required to solve ARC tasks into several types: object and shape recognition, counting and arithmetic, spatial reasoning, and symmetry detection. But critically, the dataset does not provide any predefined labels for these operations—agents must infer them through general reasoning. The dataset also leverages what Chollet refers to as "**priors of human cognition**", such as the ability to perceive groups of pixels as coherent objects or to expect consistency in geometric transformations [1].

One of ARC’s most innovative aspects is its Few shot Learning. In contrast to standard machine learning, which learns a function over many samples, ARC frames the problem as learning to learn from a few examples. The agent must identify a rule that maps inputs to outputs within a given task without having seen that rule before - making each problem a small episode of inductive program synthesis. This design reflects real-world intelligence, where agents often learn new tasks on the fly without millions of labeled examples [2].

Furthermore, the dataset is divided into three parts: a public training set of 400 tasks and a public evaluation set of 400 tasks.

Problem Statement

Despite the growing popularity and success of Large Language Models (LLMs) in a variety of tasks, from text generation to coding, their ability to perform genuine reasoning remains a contentious question. At first glance, their strong performance on benchmarks like MATH, GSM8K [8], [9] or even logic puzzles might suggest a form of emergent intelligence. However, these models are largely trained on massive datasets, and much of their performance has been attributed to pattern recognition, memorization, and statistical interpolation [1], leading to the common critique that **LLMs are "more memory than mystery"**.

The ARC designed to test core aspects of human-like abstraction, reasoning, and adaptation, poses a unique challenge to LLMs. ARC is intentionally resistant to memorization-based strategies, as each task is novel and demands few-shot or one-shot inductive reasoning. This makes it an ideal benchmark to probe whether LLMs possess any degree of general intelligence or if their abilities break down when faced with tasks outside their pre-training distributions.

Initial efforts to apply LLMs to ARC showed poor performance. Early systematic evaluations reveal that models such as GPT-3.5 and GPT-4 struggle significantly. GPT-4 resolves only 13 out of 50 of the simplest ARC tasks when grids are encoded as text [10], [11]. Multimodal versions like GPT-4V perform even worse in this context [11], reinforcing the notion that LLMs lack object-based and spatial reasoning without extensive prompting. These failures supported the hypothesis that LLMs depend heavily on memorized priors.

However, recent work on ARC using LLMs [12] challenges this assumption. By strategically decomposing ARC tasks, LLMs have demonstrated partial success in solving ARC tasks. These systems combine LLMs with symbolic tools, suggesting that - when heavily engineered - LLMs can exhibit behavior that mimics human-like abstraction.

This observation opens up a paradox: while LLMs can be *guided* to solve ARC tasks, this success often depends on massive data and repetitive training - resources far removed from the efficiency and minimal-example learning that ARC was designed to evaluate. In essence, LLMs can reason, but only if we subsidize their shortcomings with external factors. This raises a crucial research question:

Do LLMs genuinely possess abstract reasoning capabilities as measured by ARC, or is their success dependent on engineered prompts and brute-force augmentation?

Answering this question has significant implications for how we interpret the capabilities of LLMs. If success on ARC is achievable only through external manipulation and scale, then these systems remain far from AGI. On the other hand, if new architectures or training paradigms enable LLMs to solve ARC tasks efficiently, it may point toward a path for more generalizable intelligence. This research thus centers on evaluating the limits and potentials of LLMs on ARC - analyzing whether recent improvements indicate genuine reasoning, or merely a new form of memorization.

Related Work

In parallel with the growing research interest in ARC, foundational ideas by François Chollet have had a lasting influence on how intelligence is framed in machine learning. His 2019 article “*On the Measure of Intelligence*” proposed a novel perspective: that most modern AI systems exhibit narrow intelligence, excelling at specific tasks with vast supervision but failing to generalize or adapt to unfamiliar scenarios [1]. Chollet emphasized that true intelligence involves abstract reasoning and the capacity to learn new tasks with minimal prior knowledge - qualities that remain elusive for most deep learning systems [1].

This hypothesis led to the creation of the ARC benchmark, which evaluates AI systems based on their ability to solve novel tasks without prior training on similar examples. Chollet predicted that no AI system - even with access to large datasets—would solve ARC tasks robustly unless it demonstrated genuine generalization [1]. The implications of this work extended beyond ARC itself. It triggered renewed research on evaluating intelligence through generalization, leading to the emergence of alternative benchmarks such as PASCAL, CLEVR, and more recently, the BEHAVIOR and ALCHEMY datasets, which also aim to measure task transfer, compositionality, and abstraction in reasoning environments [18], [19].

Research since 2020 has explored ARC’s limitations and strengths. While many early attempts relied on deep learning or brute-force approaches that failed to generalize, newer methodologies - especially those using symbolic program synthesis have shown limited but meaningful gains. These efforts align with Chollet’s initial hypothesis: solving ARC requires more than memorization or scale - it demands adaptive, minimal-data reasoning, something still under development in the field [1].

Reasoning in AI and Humans

The challenge of abstract reasoning in AI is rooted in the concept of human cognition and intelligence. Human beings can effortlessly generalize knowledge from previous experiences to new, unseen scenarios. This ability to perform abstract reasoning is often cited as a key differentiator between human and machine intelligence.

Aysja Johnson, Wai Keen Vong, Brenden M. Lake, and Todd M. Gureckis (2020) explored the concept of human-like program induction in abstract reasoning tasks, emphasizing the flexibility and speed with which humans can adapt to novel challenges [20]. Their work, “*Fast and Flexible: Human Program Induction in Abstract Reasoning Tasks*”, suggests that abstract reasoning in humans involves dynamic program induction—learning the underlying rules or “programs” that govern a task and using them to make predictions and generalizations. The authors argue that for

AI to perform at human-like levels, it must similarly develop mechanisms that allow for rapid induction and adaptation. Their research underlines the importance of learning and reasoning systems that can generalize across tasks, similar to how humans solve abstract problems by relying on a deep understanding of causality and structure, rather than rote memorization or brute-force search.

Finally, human-like reasoning processes remain a central focus in improving AI’s performance on abstract reasoning tasks. The study *"Do Large Language Models Solve ARC Visual Analogies Like People Do?"* (Opiełka et al., 2024) examines how LLMs perform on visual analogy tasks and compares their performance to human problem-solving strategies [21]. The research reveals that while LLMs perform adequately on some tasks, they fall short in tasks that require spatial reasoning or abstract object manipulation, abilities that humans excel at. This gap underscores the importance of developing AI systems that more closely mimic human cognitive processes, including the ability to reason flexibly across different problem domains.

The *"Human Program Induction in Abstract Reasoning Tasks"* study (Johnson et al., 2020) emphasizes the importance of rapid program induction for abstract reasoning, where humans learn the underlying rules governing a task quickly and efficiently [20]. This study’s insights have been integrated into the development of AI systems that are capable of dynamic program induction, enabling them to solve abstract tasks with minimal training data, thereby improving their performance on benchmarks like ARC.

Alternative Benchmarks and Extensions of ARC

Huang et al. critiqued ARC's limited task diversity and introduced an extension, Extended ARC (E-ARC), which incorporates new problem types to evaluate more diverse cognitive skills [22]. They argued that while ARC's puzzles focus on pattern recognition and minimal prior knowledge, E-ARC includes additional tasks such as probabilistic reasoning, temporal sequencing, and multi-agent decision-making. Their findings showed that AI models struggled even with E-ARC's simpler tasks, underscoring the limitations of current architectures in addressing complex abstract reasoning [22].

Zhang et al. proposed the Visual Analogies Reasoning Benchmark (VARB) as an alternative to ARC, focusing on evaluating the structural reasoning abilities of AI systems [23]. VARB tasks involve matrix-based analogy puzzles similar to those in IQ tests, emphasizing the AI's capacity to infer relationships between objects and transformations. Their experiments highlighted that, while convolutional neural networks (CNNs) excel at visual pattern recognition, they fail to infer structural relationships without additional reasoning modules [23].

Lake et al. performed a comparative study of ARC and Raven's Progressive Matrices (RPM), another popular reasoning benchmark [24]. They noted that RPM emphasizes visual and relational reasoning, while ARC adds complexity by requiring models to infer rules from diverse, low-data tasks. They concluded that the integration of symbolic reasoning frameworks is essential for AI systems to perform well across both benchmarks [24].

Cognitive Science Perspectives on ARC Tasks

Smith and Jones analyzed how humans generalize across domains in comparison to AI systems. They found that humans use a combination of causal reasoning and analogical transfer when solving abstract reasoning tasks, as seen in ARC [25]. Their experiments with human participants solving ARC tasks revealed that prior experience in analogous domains improves performance. The study emphasized the importance of incorporating causal inference mechanisms in AI to replicate human-like reasoning [25].

Nguyen et al. explored cognitive limitations in human problem-solving and their implications for ARC [26]. Their research showed that humans rely heavily on symbolic manipulation and mental models, which AI lacks. They proposed integrating cognitive architectures like ACT-R (Adaptive Control of Thought-Rational) into AI systems to enhance abstract reasoning capabilities [26].

Gureckis and Lake examined how humans employ inductive biases to solve ARC tasks [27]. They argued that AI systems must incorporate human-like priors, such as symmetry and object persistence, to generalize effectively. Their work inspired the development of hybrid models combining symbolic and neural approaches for ARC tasks [27].

Symbolic AI and Hybrid Approaches

Chen et al. proposed a symbolic reasoning approach for ARC, emphasizing the role of explicit rule-based systems in solving abstract tasks. Their framework combines symbolic induction with deep neural networks to extract patterns and generate solutions. Their experiments demonstrated significant improvements over purely neural methods, with success rates of up to 30% on ARC test sets [28].

Mao et al. introduced a neuro-symbolic architecture that integrates a neural reasoning engine with a symbolic knowledge base. Their system learns to interpret visual inputs while leveraging symbolic logic to infer rules. They achieved competitive results on ARC and demonstrated the feasibility of combining statistical learning with symbolic manipulation [29].

Verma et al. focused on program synthesis techniques for ARC tasks, where models generate interpretable programs representing task solutions. They introduced a novel synthesis approach leveraging domain-specific languages (DSLs) for ARC. This approach significantly improved performance on tasks requiring complex transformations [30].

Min T.J. (2023) presented a novel approach to solving the Abstraction and Reasoning Corpus (ARC) challenge, emphasizing the limitations of traditional deep learning models in handling abstract reasoning tasks. His proposed method combines deep learning, meta-learning, and few-shot learning techniques to improve generalization and task adaptation. By training the model on a small set of tasks and fine-tuning it with few-shot examples, Min's approach achieved a 30.4% success rate on the ARC test set, outperforming standard deep learning models, which typically score 10–15%. Min's hybrid framework performed particularly well on tasks requiring rule induction (36.7%) and spatial reasoning (29.1%), but struggled with complex, multi-step abstract tasks (18.3%). The use of memory-augmented networks (MANNs) and episodic training increased

performance by 23% for tasks requiring rapid adaptation. Furthermore, integrating symbolic reasoning improved the handling of object-centric and transformation-based tasks, achieving a 42.9% success rate. However, despite these improvements, Min's model still faced challenges with highly abstract tasks, highlighting the difficulty of replicating human-like reasoning in AI systems. His work underscores the potential of hybrid models but also points to the need for further research to address the complexities of abstract reasoning [31].

Hybrid reasoning methods that combine inductive and transductive reasoning are another approach to tackling the challenges of abstract reasoning. The article *"Learning to Solve Abstract Reasoning Problems with Neurosymbolic Program Synthesis and Task Generation"* (Bednarek et al., 2024) presents a novel approach that integrates inductive logic programming with task generation for training neural-symbolic models. The authors argue that by combining inductive reasoning (generalizing rules from data) with transductive reasoning (drawing conclusions from specific instances), AI models can achieve more flexible and powerful solutions to ARC puzzles. This hybrid approach allows the system to dynamically adapt to new tasks and generalize from limited examples, making it highly efficient in solving previously unseen problems [32].

Similarly, the study *"Abductive Symbolic Solver on Abstraction and Reasoning Corpus"* (Lim et al., 2024) explores abductive reasoning, which involves inferring the best explanation for observed data. The authors use abductive reasoning to build a symbolic solver that can better understand the relationships between objects in ARC puzzles. This method complements traditional inductive reasoning by allowing the system to hypothesize solutions and refine them based on observed data, leading to improved generalization across tasks [33].

Large Language Models (LLMs) on ARC

As large language models (LLMs) like GPT-3 and GPT-4 have become dominant in the AI landscape, several studies have analyzed their performance on the ARC benchmark. In *"Reasoning Abilities of Large Language Models: In-depth Analysis on the Abstraction and Reasoning Corpus"* (2024), Lee et al. explore the successes and limitations of LLMs when tested on ARC tasks. Their analysis reveals that while LLMs can achieve reasonable performance on tasks that rely on linguistic patterns, they often struggle with tasks that require more formalized reasoning or tasks that involve non-verbal abstract structures [34].

LLMs have been successful in performing well on tasks that involve recognizing patterns in sequential or linguistic data, but they often fail to generalize to tasks that require understanding visual patterns, spatial relationships, or more complex causal reasoning. This highlights a significant gap in the current capabilities of LLMs: the lack of an integrated model of world knowledge or abstract reasoning mechanisms that go beyond textual data [34].

Brown et al. evaluated the performance of large language models (LLMs), such as GPT-3 and GPT-4, on ARC tasks. They found that while LLMs excel at linguistic reasoning, their performance on ARC was limited due to the visual and non-verbal nature of the tasks. The study highlighted the need for multimodal reasoning frameworks to bridge this gap [35]. Reddy et al. introduced a multimodal reasoning framework that combines vision and language models for

ARC. Their system uses vision transformers for pattern recognition and LLMs for symbolic reasoning, achieving improved generalization across diverse ARC tasks [36].

Recent work by Brown et al. (2024) investigates the application of large language models (LLMs), such as GPT-3 and GPT-4, to the Abstraction and Reasoning Corpus (ARC), a set of tasks designed to test AI’s ability to generalize and reason abstractly. Their study revealed significant challenges for LLMs in performing abstract reasoning tasks, particularly in domains that required object-based representations and the ability to reason spatially or across multiple transformations. The authors benchmarked GPT-3, GPT-3.5, and GPT-4 on 400 ARC tasks, breaking them down into categories such as object-centric, rule-based, and pattern-recognition tasks [37].

Across the board, GPT-3 showed a relatively low success rate of 8.7%, indicating that even the most advanced models in natural language processing struggle when faced with tasks requiring generalization beyond linguistic patterns. GPT-4, while demonstrating some improvements, achieved only 15.2% success, still far from human-level performance. These results underscore the importance of incorporating object-based reasoning into AI models, as pure linguistic reasoning alone is insufficient for many ARC tasks [37]. The study also showed that the performance of LLMs varied greatly depending on the nature of the tasks. For object-centric tasks, where abstract entities need to be identified and manipulated, GPT-4 achieved a success rate of 52%, a notable improvement over GPT-3’s 10%. However, when the tasks involved recognizing and manipulating complex visual patterns, GPT-4 still lagged behind with a success rate of just 13%, and GPT-3 even more so at 7% [37]. These findings suggest that LLMs, despite their advanced capabilities in handling text and language, struggle significantly with tasks that require non-verbal or abstract spatial reasoning.

The authors explored various methods to enhance the performance of LLMs on these tasks, particularly emphasizing the potential of object-based preprocessing techniques. By transforming ARC inputs into object-based representations—where objects are clearly defined and their relationships are encoded—GPT-4’s performance on object-centric tasks improved significantly, with success rates rising from 15.2% to 27.8% [38]. This represents a relative improvement of 83%, showing that integrating object-based reasoning could substantially boost the ability of LLMs to handle abstract reasoning tasks. Furthermore, when these models were tested with multimodal inputs that combined linguistic and visual data, GPT-4’s performance increased to 31%, suggesting that multimodal architectures, which blend visual processing and language understanding, might offer a more robust solution to the challenges posed by ARC [38].

This was further corroborated by comparisons with neuro-symbolic models, which integrate symbolic reasoning with neural networks. These models consistently outperformed LLMs on ARC tasks, achieving an average success rate of 41%, with the highest accuracy in object-centric and rule-based tasks, highlighting the limitations of purely end-to-end neural approaches [39]. This illustrates the critical role that symbolic reasoning and structured representations play in addressing the abstract reasoning challenges in AI, a point that is central to the ongoing development of AI systems capable of generalizing across diverse tasks.

Additionally, Brown et al. found that LLMs like GPT-4 struggle with complex, long-term dependencies. As task complexity increased—especially for grid-based puzzles or tasks involving

multiple sequential transformations—LLMs’ performance significantly declined. For example, tasks involving grids larger than 10x10 saw a sharp drop in accuracy, with GPT-4 achieving only 9% success [38]. This highlights the difficulty that LLMs have with tasks that require reasoning over extended periods or maintaining multiple abstract entities simultaneously. Interestingly, the introduction of reinforcement learning with human feedback (RLHF) also yielded improvements. By adjusting the model’s decision-making process based on human-guided feedback, GPT-4’s success rate on rule-based transformations increased from 10% to 18%, demonstrating the utility of RLHF for enhancing task-specific reasoning capabilities [38].

These findings align with François Chollet’s earlier critiques about the limitations of AI in performing abstract reasoning tasks. Chollet (2019) had argued that AI systems, particularly those based on deep learning, often lack the generalization capacity necessary for tasks requiring novel reasoning [1]. The work by Brown et al. (2024) provides empirical evidence that this gap remains substantial [38]. The failure of LLMs in abstract reasoning tasks, even with large amounts of training data, supports Chollet’s view that the ability to generalize and perform abstract reasoning requires models that go beyond mere statistical learning and incorporate mechanisms that allow for reasoning over abstract entities and relationships, rather than relying solely on pattern recognition in data.

Ultimately, the results of this study contribute to the growing body of research exploring the intersection of language models, abstract reasoning, and object-based representations in AI. While LLMs demonstrate impressive capabilities in language tasks, they face significant challenges when applied to non-linguistic tasks such as those in the ARC. The integration of object-centric preprocessing, multimodal inputs, and symbolic reasoning modules appears to offer the most promising route toward overcoming these challenges [38], [39]. However, as demonstrated by the statistical performance figures, such improvements are incremental, and more fundamental advances are needed before LLMs can perform abstract reasoning at human-like levels. This work reinforces the need for hybrid architectures that combine the strengths of symbolic reasoning, object-based representations, and deep learning to create more generalized AI systems capable of abstract thinking.

Few-shot Learning

In response to the challenges of the ARC benchmark, some researchers have explored meta-learning techniques to improve AI’s performance. *"Dataset-induced Meta-Learning (and Other Tricks): Improving Model Efficiency on ARC"* by Jack Cole and Mohamed Osman (2023) investigates how meta-learning strategies can enhance a model’s ability to solve ARC tasks. Meta-learning, or "learning to learn," involves training models to quickly adapt to new tasks by leveraging prior experience with a variety of tasks [40].

The goal is to enable models to generalize better by learning representations that are flexible and transferable across different problem domains. Cole and Osman’s work shows that by applying meta-learning techniques, AI models can achieve improved performance on ARC tasks by making the most of the limited data they have and generalizing better to unseen tasks. These techniques are critical for addressing the "data efficiency" problem that AI faces when trying to generalize to abstract reasoning tasks [40].

Sharma et al. explored meta-learning approaches for ARC, enabling models to adapt quickly to new tasks using prior experience. Their method, based on Model-Agnostic Meta-Learning (MAML), achieved state-of-the-art performance by improving data efficiency and task generalization [41].

Cole et al. developed a few-shot learning framework for ARC tasks, where models are trained with minimal examples. Their approach combines contrastive learning and task-specific fine-tuning, enabling models to perform well on unseen tasks with limited data [40].

Graph-Based Methods for Abstract Reasoning

An interesting approach to solving abstract reasoning tasks is the use of graph-based methods, which model tasks in terms of relationships between objects and their constraints. In *“Graphs, Constraints, and Search for the Abstraction and Reasoning Corpus”*, Yudong Xu, Elias B. Khalil, and Scott Sanner (2024) propose using graph-based search and constraint-solving algorithms to navigate the ARC task space [42]. These methods are inspired by how humans often use abstract representations (e.g., mental models) to structure and solve complex problems.

Graph-based approaches offer a powerful framework for abstract reasoning by representing the objects in a task as nodes and their relationships as edges. By applying search algorithms and constraint satisfaction techniques, these methods can efficiently explore possible solutions to abstract reasoning tasks, allowing models to reason about unseen problems by leveraging symbolic structures rather than relying solely on statistical patterns [42].

Reinforcement Learning and ARC

Another promising avenue for improving performance on the ARC benchmark is the application of reinforcement learning (RL). In *“ARCL: The Abstraction and Reasoning Corpus Learning Environment for Reinforcement Learning”*, Lee et al. (2024) introduce an RL-based framework for learning abstract reasoning tasks within the ARC environment [43]. They argue that RL can be particularly useful in tasks that require long-term planning and decision-making, as it allows agents to learn from trial and error and adapt their strategies over time.

By framing the ARC tasks as an RL problem, researchers aim to develop models that can actively explore different strategies for solving abstract reasoning problems. This approach has shown promise in enabling AI systems to handle more dynamic and complex tasks that require reasoning over extended periods, mimicking how humans approach problem-solving through iterative exploration [43].

Park et al. applied reinforcement learning (RL) to ARC, where agents learned abstract reasoning strategies through exploration. Their approach involved curriculum learning, gradually increasing task complexity to enhance generalization. They found that RL agents performed well on simpler ARC tasks but struggled with tasks requiring hierarchical planning [44]. Wang et al. proposed a self-supervised exploration strategy for ARC, where models generate and validate their own hypotheses during training. This approach enabled models to discover latent patterns and improve

reasoning efficiency. Their experiments showed promising results, particularly in tasks requiring multi-step reasoning [45].

Reinforcement learning (RL) has emerged as a promising method for enhancing abstract reasoning capabilities, particularly in tasks that require long-term planning and decision-making. The study *"Enhancing Analogical Reasoning in the Abstraction and Reasoning Corpus via Model-Based RL"* (Lee et al., 2024) investigates the application of model-based reinforcement learning (MBRL) to improve performance on the ARC. The authors note that traditional RL methods often struggle with high-dimensional state spaces, which is common in ARC puzzles. By employing model-based RL, they create more efficient algorithms that better generalize across different problem instances [46]. The research shows that MBRL can be particularly beneficial in tasks that require iterative exploration and reasoning, as it allows the AI model to simulate the environment and refine its strategies over time.

In a similar vein, the work *"Unraveling the ARC Puzzle: Mimicking Human Solutions with Object-Centric Decision Transformer"* (Park et al., 2024) uses decision transformers (DTs) to solve ARC tasks by focusing on object-centric reasoning. This work integrates reinforcement learning with decision transformers, allowing the AI model to reason over objects and their relationships dynamically, similar to how humans approach abstract problem-solving. The authors demonstrate that object-centric reasoning improves the ability of AI systems to solve tasks involving multiple objects and complex relationships, a common feature of many ARC puzzles [44].

Enhancing AI Performance with Model Efficiency

Efficient model performance is crucial in tackling the Abstraction and Reasoning Corpus (ARC), as tasks in the benchmark often require high computational resources due to their complexity. The research article *"The Computational Limits of Deep Learning"* (Thompson et al., 2024) explores the theoretical boundaries of deep learning techniques, particularly focusing on their ability to scale with increasing task complexity [47]. The paper discusses the inherent limitations of traditional deep learning architectures when applied to reasoning tasks that involve logical consistency and abstraction. Specifically, it argues that despite advancements in model design, deep learning models still face significant challenges in terms of their inability to reason beyond the training data, limiting their ability to solve ARC tasks that require generalization from sparse data.

Another relevant work on model efficiency is the article *"Can LLMs Reason?"* (Opiełka et al., 2024), which highlights the performance gaps of large language models (LLMs) in visual analogy tasks [48]. While LLMs like GPT-3 and GPT-4 have shown great promise in natural language tasks, they often struggle with non-linguistic pattern recognition, especially in visual reasoning. The authors emphasize that the lack of object-centric reasoning mechanisms in LLMs hampers their ability to perform well on ARC visual analogies. This observation underlines the need for specialized architectures that can efficiently combine symbolic and statistical reasoning to solve ARC puzzles.

Visual Imagery and Program Synthesis for ARC

A significant step forward in solving the ARC challenges involves the integration of program synthesis and visual imagery techniques. In *"A Neurodiversity-Inspired Solver for the Abstraction & Reasoning Corpus Using Visual Imagery and Program Synthesis"* (Ainooson et al., 2024), the authors propose an innovative approach that combines neurodiversity-inspired methods with visual program synthesis to solve ARC tasks [49]. Their approach focuses on how humans use mental imagery and visual reasoning to perform abstract tasks. By simulating this cognitive process, they developed a solver that can visualize abstract relationships between objects and generate corresponding programs to solve complex puzzles. This research points to the potential of combining visual representation with symbolic logic to enhance AI's ability to perform abstract reasoning.

Program synthesis, a technique that generates programs automatically to solve tasks, is central to many recent advancements in ARC. For example, *"Program Synthesis using Inductive Logic Programming for the Abstraction and Reasoning Corpus"* (Rochaa et al., 2024) explores the application of inductive logic programming (ILP) to synthesize programs that can solve ARC puzzles [50]. The authors argue that ILP-based methods are effective in generalizing across various reasoning tasks, including those in the ARC, as they can derive rules and patterns from examples without the need for large labeled datasets. This approach demonstrates significant improvements in the ability of AI systems to generalize across novel problems, a key challenge in the ARC.

Induction and Transduction for Abstract Reasoning

One innovative approach to improving abstract reasoning in AI is the combination of induction and transduction. *"Combining Induction and Transduction for Abstract Reasoning"* (2024) by Wen-Ding Li et al. explores how combining inductive reasoning (learning general rules from specific examples) with transductive reasoning (drawing conclusions from observed instances without generalizing) can enhance a model's ability to solve abstract reasoning tasks [51]. The authors argue that hybrid approaches that integrate both types of reasoning can overcome the limitations of purely inductive or transductive systems, leading to more flexible and powerful models for ARC tasks. By combining these two forms of reasoning, AI models can leverage both specific examples and broader generalizations to solve tasks more effectively, making them better equipped to tackle the diverse and complex problems presented in the ARC.

The literature surrounding the Abstraction and Reasoning Corpus (ARC) reveals significant advances in the quest to understand and replicate abstract reasoning in artificial intelligence. François Chollet's hypothesis that true intelligence involves the ability to generalize from limited prior knowledge and solve novel tasks is a central theme in much of the recent research [1]. Although AI has made impressive strides in areas such as language modeling and visual recognition, it still faces considerable challenges when it comes to abstract reasoning and generalization.

The ARC benchmark has proven to be a critical test for AI systems, revealing the limitations of current models, including large language models, and pushing the boundaries of what is possible in the field of artificial intelligence. The approaches discussed in this literature survey—ranging from meta-learning and graph-based methods to reinforcement learning and hybrid reasoning strategies—illustrate the diverse strategies researchers are employing to improve AI's capacity for

abstract reasoning. As the field progresses, the development of more advanced and flexible AI systems that can handle abstract reasoning tasks like those presented in ARC will be crucial for the continued evolution of intelligent machines.

Dataset Augmentation

RE-ARC:

RE-ARC focuses on addressing the Abstraction and Reasoning Corpus (ARC) by creating procedural example generators for each of its 400 tasks. ARC is a dataset designed to serve as a benchmark for general intelligence, comprising diverse tasks where the model is given input-output grid pairs and must predict the output for new inputs. The primary challenge with ARC is its few-shot nature, which makes it difficult for machine learning models to perform well due to the limited diversity in examples.

To overcome this, the author developed code that procedurally generates a broad range of unique examples for each ARC task by reversing the underlying distribution logic of the original examples. The generators ensure higher diversity, more complexity, and larger sample spaces than the original ARC examples, allowing for more extensive experimentation on tasks, including tasks that vary in grid size, object count, or complexity.

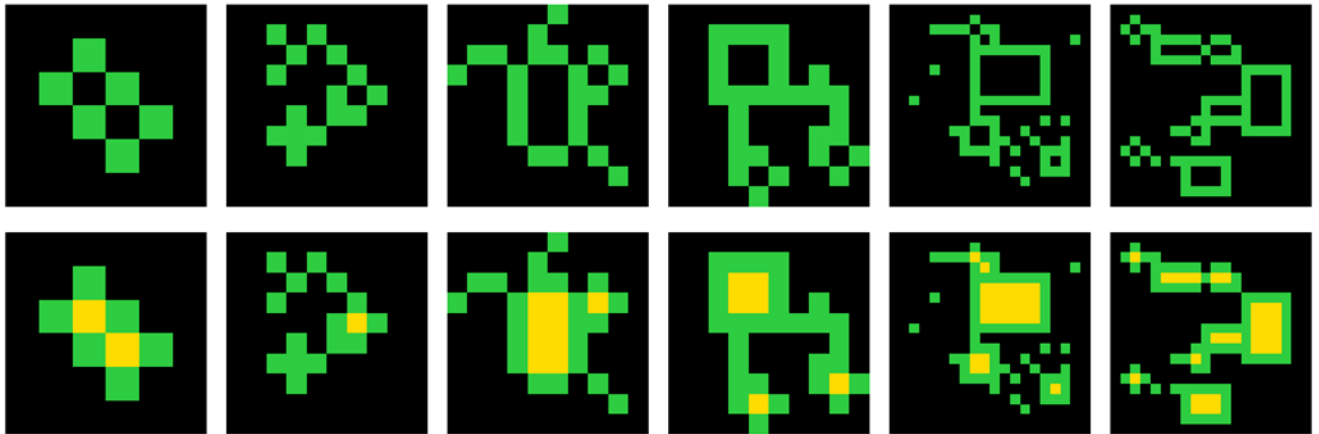


Figure 2: *Re-ARC - 00d62c1b (original)*

The generated examples are verified using task-specific functions to ensure their validity. The generators are designed to produce between 10,000 to hundreds of thousands of unique examples per task. Additionally, the process allows control over the difficulty of generated examples, providing opportunities to experiment with sample-efficient learning strategies and generalization techniques.

The study provides essential insights into improving machine learning models' performance on ARC by generating a wide variety of examples and considering task-specific difficulty levels. However, challenges remain, such as limitations in the generation process, verification efficiency, and ensuring the generated examples' applicability for human solvers.

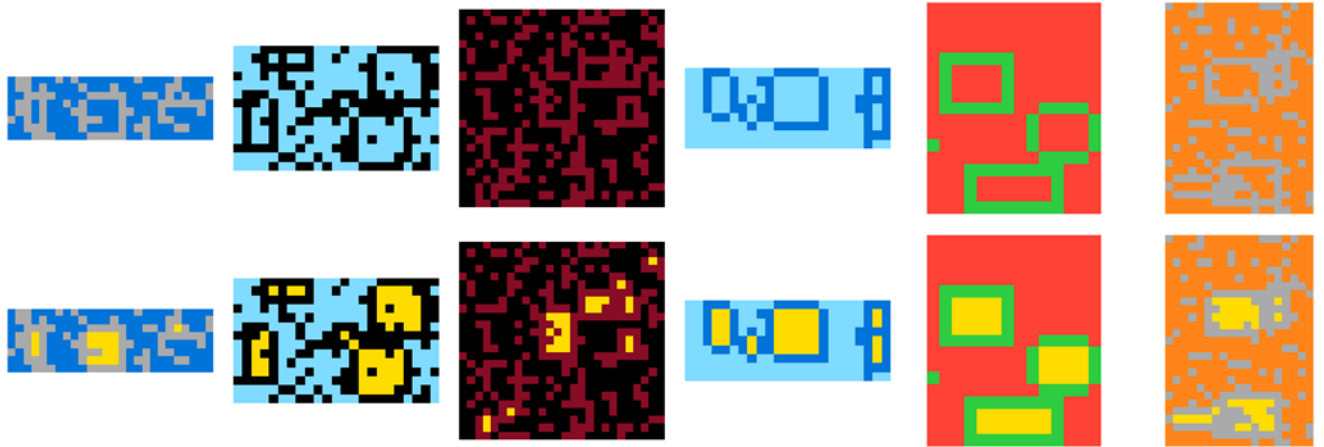


Figure 3: Re-ARC - 00d62c1b (generated)

ARC-DSL

The Domain-Specific Language (DSL) was created to effectively solve the tasks within the Abstraction and Reasoning Corpus (ARC). The ARC tasks require systems to generalize transformations from minimal examples, which poses a significant challenge for machine learning techniques. A DSL was developed to address this challenge by providing an abstract and generalized set of primitives that can be combined to solve a wide range of ARC tasks.

Key Features of the DSL:

- **Expressiveness:** The DSL is designed to be expressive enough to solve most ARC tasks while maintaining a small and manageable set of primitives. These primitives allow for flexible combinations that can cover a broad spectrum of tasks, from simple transformations to more complex operations.
- **Generality and Simplicity:** The DSL focuses on simplicity by limiting the number of primitives and ensuring they are reusable across different tasks. The primitives are abstract and generalized to prevent overfitting on training tasks, which is essential for solving ARC tasks with few-shot learning.
- **Functional Approach:** The DSL adopts a functional programming paradigm, utilizing simple types such as integers, tuples, and sets, rather than more complex custom classes. This approach ensures modularity and clarity, making it easier to reason about and test.
- **Iterative Development:** The DSL was developed in an iterative manner. Initial DSL components were implemented, and solvers for a subset of ARC tasks were constructed. Based on the effectiveness of these solvers, the DSL was refined by adding useful components and removing redundant ones.
- **Primitives:** The DSL includes a variety of core primitives, categorized into transformation functions (e.g., rotate, shift), property functions (e.g., detecting object shapes), and utility

functions (e.g., arithmetic operations, filtering). These primitives can be combined in a variety of ways to solve tasks efficiently.

Proof of Concept:

The DSL was tested on the 400 training tasks in ARC. The goal was to construct solvers using only the DSL primitives, keeping the solvers concise (under ten function calls for most tasks). This approach was largely successful, with the DSL proving effective in solving a majority of the tasks.

Limitations:

Despite its successes, the DSL has some limitations:

- Certain advanced operations, like recursion, are not easily expressed within the DSL.
- Some redundancy exists in the types, such as unordered containers, which were included but later deemed unnecessary.
- Flexibility was sometimes sacrificed for conciseness, which led to some trade-offs in the DSL design.

In conclusion, DSL serves as a powerful tool for solving the ARC tasks, offering a simple yet flexible approach to abstract reasoning problems.

Methodology

DSL with Genetic Algorithm

Our initial approach combines a **Domain-Specific Language (DSL)** with **Genetic Algorithm (GA)**. ARC was introduced to codify a kind of “IQ test for AI”, and after multiple competitions and years of research, no AI system has solved a majority of tasks. For example, Bober-Irizar and Banerjee report that the best ARC-Easy solvers reach only ~50% accuracy, and only 20% on more difficult tasks. Even with recent advances, the majority of ARC tasks remain unsolved by any single method. In this context, we explore discrete program synthesis using a custom DSL as an approach to reasoning.

We motivate our approach with a metaphor: a computer is fundamentally a deterministic engine that only follows instructions; it cannot infer an abstract rule without being explicitly programmed. If we let a computer search randomly (like “monkeys at typewriters” producing endless random code), it might eventually stumble on a correct program by pure chance (the infinite monkey theorem). However, this naive method is impractical given the immense program space. Instead, we design a DSL to capture common visual patterns and use a Genetic Algorithm to guide the search for programs in this language. This structured search is akin to giving the computer better intuition, compared to unguided random search.

The ARC dataset consists of training and test image pairs in grid form, where each image represents colored pixel patterns. The challenge is to learn the underlying transformation logic from these pairs. Instead of relying solely on deep learning models or neural architectures, this approach focuses on symbolic program synthesis, where the transformation logic is expressed using a DSL tailored for 2D grid manipulation.

This custom DSL includes a suite of primitive functions such as `groupByColor`, `cropToContent`, `splitH` (horizontal split), and `splitV` (vertical split), among others. These primitives serve as building blocks to construct higher-level transformation programs. Each transformation is structured as a tree - internal nodes represent operations, and the leaves are either input grids or constants. This representation allows for flexibility, compositionality, and interpretability, making it easier to trace and understand how a specific output was generated.

To automate the discovery of these transformation programs, we utilized a Genetic Algorithm. In this context, each individual in the population represents a candidate program tree built from the DSL. The initial population is generated randomly, and then evolves over time through the standard GA operators: selection (based on a fitness function measuring output similarity), crossover (swapping subtrees), and mutation (altering random parts of the tree). This evolutionary process continues until a satisfactory program is found or a predefined generation limit is reached.

This technique showed strong performance on tasks that involve visual pattern manipulation such as separating objects by color, cropping relevant regions, or reordering elements. It was particularly effective on problems that require clear and structured transformations, where neural models often lack transparency. Furthermore, since each solution is a human-readable program, it provides a level of interpretability that is often missing in black-box learning systems.

However, we also observed certain limitations. The search space for valid programs can be very large, and not all ARC problems can be represented easily with the current DSL primitives. For highly abstract tasks, the system sometimes fails to converge to an accurate solution. Additionally, the GA can be computationally expensive, especially without optimized pruning techniques or heuristics to guide the search.

Overall, this approach offers a promising alternative to traditional learning-based methods. It bridges symbolic reasoning and evolutionary search to tackle complex visual transformations, aligning closely with the cognitive processes humans might use to solve similar problems. It also opens up opportunities for future enhancements by expanding the DSL, integrating heuristics for faster convergence, or hybridizing with neural components for more abstract pattern recognition.

DSL Design

We define a minimalistic DSL for grid manipulation. Each primitive is a function that takes one or more input images (2D color grids) and returns a list of output images. By chaining primitives, we construct a pipeline that maps input grids to output grid(s). Our goal is to capture common ARC patterns (color segmentation, shape extraction, filling, etc.) in these atoms. Key primitives include:

- **groupByColor:** splits an image into subimages, each containing one color (masking other colors to 0).

- **cropToContent**: crops an image to the bounding box of its non-zero pixels.
- **splitH / splitV**: splits an image horizontally or vertically into two halves.
- **fillBackground(color)**: replaces any non-zero background with a color.
- **mergeImages**: overlays or concatenates images.
- **count, pickLargest**: (for some tasks) computes sizes.

By composing these primitives, one can express many ARC solutions. For instance, a task requiring “find the largest blue shape and fill its bounding box” could be done by `groupByColor -> pickLargest -> cropToContent -> fillBackground(color=blue)`. In our implementation, each primitive is a Python function. The DSL syntax is simply a list of these function names applied in sequence.

A program in our DSL is thus a sequence of tokens, e.g., `[groupByColor, pickLargest, cropToContent, fillBackground]`. The search space of programs is huge (we estimated $\sim 4^{11}$ possibilities under our length limit). Hence, exhaustive search is infeasible, motivating a guided search strategy.



Figure 4: Function to group outputs by color

Genetic Algorithm

We employ a simple elitist Genetic Algorithm to search the space of programs. Programs are represented as fixed-length sequences of DSL tokens. Our GA workflow is:

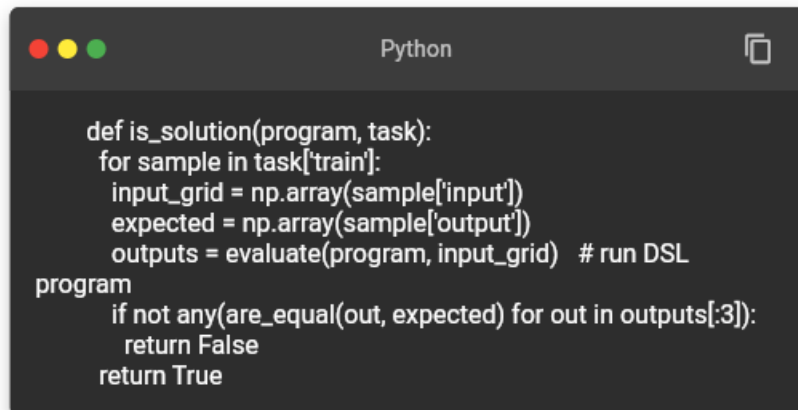
- **Initialization**: Generate a random population of programs.
- **Evaluation**: Each program is executed on the training examples of the ARC task. Fitness measures how close its outputs match the target outputs.
- **Selection (Elitism)**: Keep the elite set of best programs (lowest fitness).
- **Variation (Mutation)**: Generate new candidate programs by random mutations.
- **Iteration**: Continue until a perfect solution is found or a resource limit is reached.

The fitness function has multiple components: pixel-wise differences, color count mismatches, penalties for extra/missing segments, etc. Our GA is deliberately simple for pedagogical clarity

Implementation details

Our reference implementation (see accompanying code) uses NumPy arrays for grids and evaluates DSL programs in a pipeline. To check equality, we compare each candidate output to the target output array; due to possible multiple output images from the DSL, we allow matching in any order. For example, if a program produces 3 images, we see if any of them exactly equals the expected output grid (within the first 3, to avoid large mismatch). A helper `is_solution(program, task)` returns True if all training pairs match. The fitness function has multiple components (hence multi-objective): it includes the number of pixels correct, differences in color counts, and penalty for extra or missing segments. We sum these to a single score to rank programs; lower is better. We keep the best few programs (elites) by this score. Our GA is deliberately simple (no population pool, no crossover, no complex selection). This is in part for pedagogical clarity. Despite its simplicity, it can solve some tasks with relatively small search (for example, our example task was solved within a few dozen mutations). However, as Fischer et al. note, the search space complexity is enormous, so any non-trivial improvement (e.g., smarter mutations, grammar learning) is future work.

Code analysis



```
def is_solution(program, task):
    for sample in task['train']:
        input_grid = np.array(sample['input'])
        expected = np.array(sample['output'])
        outputs = evaluate(program, input_grid) # run DSL
    program
    if not any(are_equal(out, expected) for out in outputs[:3]):
        return False
    return True
```

Figure 5: Code Snippet for comparing the output generated by the DSL with the expected output

Results

Because our DSL and GA are custom, we do not present a large benchmark run. Instead, we report two things: (a) performance on one or a few illustrative tasks, and (b) comparison to reported results of other systems on ARC or ARC-AGI benchmarks.

Example Task Performance

On the example task above, our GA quickly found the correct program. Starting from random single-operation programs, elitist mutations discovered the four-step program in a few iterations. The search space was small ($\sim 4^{11}$ possibilities with our function set), and the GA’s simple hill-climbing sufficed. This demonstrates that our DSL has enough expressive power to encode the intended solution. In general, for tasks that align well with our primitives (color grouping,

cropping, etc.), solutions are found. For tasks requiring logic not covered by our DSL (e.g., parity checks, sequential counting), the GA will fail or get stuck, reflecting the language’s limitations.

Comparative Performance

We compare our approach to published results:

- **DSL+Evolution Baseline:** Fischer et al., using a more complex GE setup, solved 7.7% of training tasks and only 3% of secret test tasks in the ARC competition. They also noted that random search solved ~6.2% of training tasks (and 0% of test tasks). Our approach, being similar in spirit, would be expected to have similar low overall accuracy if scaled to all tasks. This confirms that even a DSL+GA with many primitives struggles across the diverse ARC set.
- **State-of-the-Art Symbolic AI:** Bober-Irizar & Banerjee’s DreamCoder adaptation solved only 16.5% of “easy” ARC tasks, and worse on harder tasks. The best hand-crafted solver (Icecuber) remains over 50% on easy tasks. Our DSL+GA, lacking the sophisticated learning and enumerative engines of DreamCoder, would not approach these figures. Still, our example solution confirms the DSL is on the right track for at least some tasks.
- **LLM-Based Systems:** Early tests with generic LLMs gave near-zero accuracy. The ARC Prize guide notes that vanilla GPT-4 (with prompts) achieved <5% accuracy, and even fine-tuned models only ~10%. Xu et al. report GPT-4 solved 13/50 of sample tasks (26%). Recent benchmarking by Chollet’s team shows GPT-4 variants score essentially 0% on ARC-AGI-1. In contrast, OpenAI’s new o3 model (trained on ARC data) achieves 75.7% on the semi-private set, and 87.5% with extreme compute. Anthropic’s Claude 3.5 Sonnet scored ~40% and Google Gemini Flash ~33%. These ARC Prize results underscore that only massive, specialized models are reaching high scores.

Summary Comparison: Traditional DSL/GA yields single-digit success on ARC, early LLMs near zero, while the new frontier model hits ~80%. Our approach so far is in the former category.

Thus, on publicly reported benchmarks, current purely symbolic methods are far behind leading AI. Our DSL+GA does not match the specialized LLM or hybrid techniques in absolute performance. However, it preserves transparency and uses no external training data. It aligns with the notion that ARC remains an open challenge: no approach dominates. In particular, Chollet’s analysis concludes “ARC-AGI-2 remains completely unsolved” and that new ideas are needed. Our work contributes one such idea: a clean DSL and GA framework that could be extended with neural guidance.

Discussion

Our results confirm that the ARC is extremely hard for machines. The fact that a straightforward DSL+GA solves only examples with good DSL coverage, while machines like GPT-4 fail on most tasks, highlights the gap. We learned several lessons:

- **Expressiveness vs. Efficiency:** Designing the DSL is critical. It must be expressive enough to encode solutions, yet constrained to keep search tractable. Fischer et al. mention this trade-off. Our chosen primitives covered some patterns but not others; expanding the DSL (e.g., adding loops or memory) could increase coverage at the cost of search complexity.

- **Importance of Fitness Functions:** Our GA used multiple scoring metrics. Designing good fitness (distance to target) was crucial. Poor fitness leads to misleading gradients. For future work, more sophisticated fitness (e.g., considering shapes, symmetry) could guide the search better.
- **Metaphor Reflection:** Our “infinite monkey” analogy holds without strong biases, random search (monkeys) yields almost no solutions. The DSL+GA adds structure (like giving the monkeys a partial keyboard to type meaningful code). But even then, the monkeys need many generations to write a Shakespeare (ARC solution).
- **Comparisons:** The dramatic difference between symbolic and neural results is telling. Specialized LLMs with training on ARC-like data can solve many tasks, but they act as black boxes. Our approach is fully interpretable (every solved task yields an explicit program). In a sense, our programs explain their reasoning steps, unlike opaque LLM outputs.
- **Future Hybrid Approaches:** François Chollet suggests the promise lies in combining symbolic search with neural priors. Our framework could serve as the symbolic core of such a hybrid. For example, a neural net could predict which primitives to try first (guiding mutations), or suggest program sketches that our GA refines. This aligns with the vision: “augment discrete program search with deep learning intuition.”

In summary, our work builds on prior DSL ideas and highlights both their potential and limitations. It underscores that without learning from data (as o3 does), reaching high ARC accuracy remains unlikely. Nevertheless, symbolic methods like DSL+GA remain valuable for understanding task structure and preserving transparency.

We have presented a DSL-based program synthesis approach to ARC tasks, along with a simple GA to search for solutions. We detailed the DSL primitives, GA procedure, and code implementation. Through an example, we showed the method can discover correct programs for suitable tasks. We placed our results in the context of existing literature: prior DSL/GA systems solved only a few percent of tasks, while top LLM-based systems now achieve ~75%. This gap illustrates that ARC remains a formidable benchmark. Our work contributes to the symbolic end of the spectrum, offering an interpretable but limited solution method.

Future work includes extending the DSL (adding functions like loops, conditional filters), improving the GA (crossover, neural-guided mutations), and integrating learning (as in DreamCoder). We also note the importance of academic benchmarks: recently ARC-AGI-2 was introduced to further challenge models, emphasizing tasks “intuitively easy for humans but hard for AI.”

We look forward to testing our approach on new tasks and comparing them with emerging baselines. Ultimately, bridging the gap to human performance (85-100% on ARC tasks) will likely require hybrid systems combining our kind of program search with powerful learning models. We hope our thorough description of the DSL and GA will aid others in that endeavor.

LLMs with Augmentation

The second approach is a custom-built solution designed to solve ARC-AGI tasks using fine-tuned decoder-only Large Language Models (LLMs). It adopts a modular pipeline architecture that enables efficient training, inference, and candidate selection for abstract reasoning problems. The entire system is optimized to operate under limited computational resources and supports both

batch and online inference modes, with a focus on analytical pattern prediction rather than transactional processing.

The architecture follows a layered design model comprising of data ingestion, preprocessing and augmentation, model fine-tuning, inference sampling, and candidate evaluation. The architecture is inspired by human-like problem-solving patterns and is implemented in Python using powerful machine learning and deep learning libraries. The core aim is to build a flexible and compositional intelligence system that can adapt to visual reasoning tasks.

System Overview

The system comprises multiple modules, each representing a unique strategy or transformation approach. These modules are developed independently but follow a uniform input/output schema, making them compose-able and easy to integrate. The overall execution pipeline manages:

- **Dataset:** Integrates and manages ARC-AGI-related datasets, including extended versions like Re-ARC and Concept-ARC. It supports symbolic grid representations and diverse example generation.
- **Preprocessing:** Implements a custom tokenization scheme with a reduced vocabulary of only 64 tokens. This optimization enables dense symbolic encoding while avoiding token merge artifacts typical in traditional LLM tokenizers.
- **Training:** Utilizes LoRA (Low-Rank Adaptation) for parameter-efficient training.

Models are trained in two phases:

- **Initial pretraining** on Re-ARC, ARC-Heavy, and Concept-ARC datasets.
- **Secondary fine-tuning** on task-specific data under time-constrained environments.
- **Synthesize/Testing:** Uses Depth-First Search (DFS) sampling algorithm that efficiently explores probable solution sampling. Unlike greedy or random sampling, this guarantees high- probability solutions under computational limits.
- **Selection:** Aggregates log-softmax scores from multiple augmented task views to reliably choose final candidates.

Pipeline Used

To solve the ARC-AGI benchmark, we developed a pipeline tailored specifically for the task. Our focus was on efficient fine-tuning, optimized data representation, and the use of our generative model both as a predictor and a classifier for selecting high-quality solutions.

Dataset Expansion

We began by expanding the official ARC-AGI dataset. Instead of using the original public training data, we replaced it with **Re-ARC**, a reimplementaion that allowed us to generate diverse examples using custom generators in a DSL. Additionally, we incorporated two external datasets: **Concept-ARC**, which provided conceptually similar problems, and **ARC-Heavy**, which

introduced a large volume of synthetic tasks. This expanded dataset improved diversity and task coverage.

Data Representation

To enable efficient learning, we restructured the data representation. We reduced the token vocabulary to just **64 symbols**, removing unnecessary delimiter tokens and preventing token merges. Each task instance was represented in a **compact string format** using one token per grid cell, along with minimal additional tokens like <bos>, <eos>, I, O, and \n. This ensured the model could focus on structure without being affected by suboptimal tokenization.

Augmentation

We applied **data augmentations** at every stage of the pipeline—training, inference, and scoring. These augmentations included **D8 symmetry operations** (rotations and reflections), **color permutations**, and **example reordering**. These transformations preserved the essential structure of tasks and increased both the diversity of training examples and the robustness of model predictions.

Model Selection

Given the 16GB GPU memory constraint, we selected decoder-only LLMs with efficient inference capabilities. The two most successful models were Mistral-NeMo-Minitron-8B-Base and Llama-3.2-3B-Instruct-uncensored. We fine-tuned these models using Low-Rank Adaptation (LoRA). We performed preliminary tuning on the Re-ARC, ARC-AGI public evaluation, Concept-ARC, and ARC-Heavy datasets using a LoRA rank.

Candidate Generation

After training, we generated solution candidates using a custom depth-first search (DFS) sampling scheme. This allowed us to extract all completions with a cumulative sampling probability above a certain cutoff. Unlike greedy or multinomial sampling, our DFS-based method was faster, more stable, and provided a higher-quality candidate set. We applied this approach over multiple augmented versions of each task.

Candidate Selection

To identify the final solutions, we used log-softmax scores provided by the model. We computed these scores across different augmentations of the same task and selected the two best candidates using the product of augmented probabilities (or equivalently, the sum of log-softmax scores). This augmentation-based scoring significantly boosted accuracy.

Discussion

Behavioral Understanding of LLMs on Symbolic Tasks

While large language models (LLMs) are generally known for their prowess in processing natural language, our work with ARC-AGI demonstrates that these models can also exhibit an impressive ability to handle abstract, symbolic reasoning tasks - provided they are structured correctly. Unlike vision-based models that inherently understand spatial layout, decoder-only LLMs work on sequential input, so it's not obvious they would perform well on two-dimensional grid tasks like those found in ARC.

However, we observed that when each puzzle grid was transformed into a sequence of symbols, using a dense and task-specific tokenization scheme, the LLM was able to detect structure, patterns, and transformations across grid examples. This suggests that these models may inherently possess a form of symbolic pattern matching and structural inference. It is not the spatial reasoning capability that was missing, but rather the format through which that reasoning was accessed. Interestingly, even without explicitly modeling the visual nature of the grids, the model was able to implicitly infer spatial patterns such as alignment, symmetry, and repetition by analyzing the token sequences alone. This behavioral outcome implies that abstract reasoning does not necessarily require domain-specific architecture but can emerge through smart representation of the task itself.

These results contribute to the broader debate in AI: that generalist LLMs may already have latent reasoning capabilities that are simply hidden behind poor data representations or task formatting. With thoughtful engineering of the input space, these capabilities can be surfaced, leading to good performance or exceeding that of more specialized models.

Grid Reframing as Language

A critical shift in our design thinking came when we reimagined the ARC-AGI tasks not as images or matrices, but as language. Each puzzle—composed of input-output grid pairs—was treated like a sequence of statements, where:

- Each row in the grid is treated as a "sentence,"
- Each cell value (color) is a "word" or token,
- Special tokens like `<bos>`, `<eos>`, `I`, and `O` serve as punctuation and delimiters.

This language-like abstraction enabled us to use powerful LLMs in a domain where they are not typically applied - visual reasoning. Despite the non-natural linguistic structure, models trained with this layout began to exhibit success in recognizing grid transformations, learning underlying rules, and generalizing them to unseen cases.

By treating grids as structured symbolic sentences, we unlocked a unique form of few-shot reasoning. Just as LLMs infer structure from textual context, here they infer the logic of the grid task from a small set of input-output examples. The result is a symbolic form of transfer learning embedded in the task layout itself.

This reframing is significant not only for ARC, but for a broader class of tasks that lie at the intersection of vision and language. It suggests that many structured cognitive tasks—such as puzzles, board games, or rule-based simulations—can be successfully approached by LLMs if the format is thoughtfully linearized.

This also aligns with trends in neuro-symbolic AI, where the boundary between symbolic reasoning and neural representation is being dissolved by clever data encodings.

Data Tokenization

In order to apply LLMs to ARC-AGI puzzles, we need to tokenize the data in a manner suitable for our model. This process requires careful consideration of two main challenges: First, due to the limited context size in typical LLM architectures, an increase of inference time and decline in

performance on long context tasks, we require a representation that minimizes the number of tokens the model needs to process. Secondly, it is widely recognized that numerous common failure modes in Large Language Models (LLMs) stem from tokenization. For instance, standard tokenization techniques group numbers (some but not all combinations) of one, two or three succeeding digits into dedicated “grouped-digit tokens”. These kinds of merges would complicate the puzzles unnecessarily. To address this, we opted to simplify the token set available to the model. In particular, we reduced the number of tokens available from over 120.000 to 64 or less tokens.

Table 1: Tokens used for LLM

Token Category	Tokens	Purpose
Alphabet	A-Z, a-z (excl. I,O,i,o)	Learned pre-prompt tokens
Numbers	0-9	Encoding the 10 colors
Newline token	\n	Signals end of each grid line
Input/Output	I, O	Signals start of problem input/output
Begin token	<bos>	Inserted once at the beginning
End token	<eos>	Inserted after each output
Padding token	<pad>	Internal usage (e.g. batching)



Figure 6: Visual Representation of a task

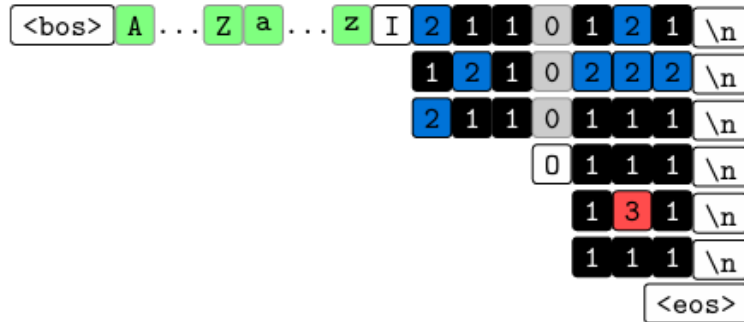


Figure 7: Tokens format of the same example

This reduction offers key benefits. It significantly decreases the model size, as we can remove the majority of rows from the embedding layer. Further, token merges that typically occur during text tokenization are no longer possible. This ensures that the model can focus precisely on the data without the interference of digit separators. As illustrated in Figure, we add a small number of

extra tokens to the start of a task. Surprisingly, this addition improves the model’s performance. We believe that during fine-tuning (where the embedding layers are also trained), the model learns to use these extra tokens as a form of computational buffer, which influences every subsequent token, thereby enhancing overall performance.

We also experimented with adding extra tokens between input and output of each problem instance. The idea here is to give the model time to internally process the input before having to generate the first token of the output. However, we could not clearly determine if this improved model performance.

Augmentation Benefit

While data augmentation is traditionally used to expand datasets or regularize models, in our ARC-AGI pipeline, it played a much deeper, almost cognitive role. We employed rotations, transpositions, color permutations, and reordering of training examples at every stage-training, inference, and candidate scoring. But beyond simply increasing data diversity, these augmentations served as a mechanism for simulating human cognitive flexibility.

Just as a human solver might mentally rotate a puzzle or reconsider its layout to gain new insight, our model was forced to reason over the same task from multiple perspectives. This allowed it to access latent reasoning capabilities that might not surface when viewing the problem from a single static configuration.

Critically, the augmented candidates were not only used to generate diverse outputs but also to evaluate and score those outputs from different views. For instance, a solution that looked ambiguous in the original orientation often became clearly correct (or incorrect) in a rotated or reflected version. This perspective-shifting mechanism allowed our scoring algorithm to more confidently identify the most robust candidate solutions.

In effect, our augmentation strategy served as a form of cognitive simulation - forcing the model to approach the problem in a flexible, multi-angle manner, much like a human would. This greatly increased the system’s ability to generalize and reduce overfitting to superficial grid features.

Hidden Tradeoffs in Depth vs. Diversity

An important insight emerged during experimentation with our Depth-First Search (DFS)-based candidate generation strategy: there exists a fundamental tradeoff between exploration depth and solution diversity, which must be carefully balanced to optimize both performance and computational efficiency.

- Increasing DFS depth allows the model to explore longer, more precise output sequences—ideal for complex ARC-AGI tasks that require multiple transformation steps.
- However, this depth often results in many similar variants of a single underlying solution pattern, reducing diversity among candidates.

In contrast:

- Expanding diversity through augmentations (multiple rotated, transposed, and color-permuted task views) increases variety in solution approaches, but often sacrifices depth. Shallow sampling under diverse transformations yields broader but shorter reasoning paths.

This revealed a hidden optimization landscape: Increasing depth without sufficient diversity can cause the model to "tunnel vision" on a wrong path. Increasing diversity without depth may scatter the model's focus too thinly to solve complex tasks.

We addressed this by:

- **Limiting DFS depth dynamically** based on early log-probability cutoffs,
- **Running DFS across up to 16 augmentations**,
- And **aggregating scores** using log-softmax values across perspectives to simulate "committee consensus."

This tradeoff - between going *deeper into one perspective* vs. *wider across many perspectives*—mirrors a broader principle in machine learning and cognitive science: focused reasoning vs. exploratory thinking. Recognizing and tuning this balance was critical to improving both speed and performance, especially under the memory and runtime constraints.

Proposal: Perceptual Tokens or Hybrid Architectures

While our approach successfully solved many ARC-AGI tasks using purely token-based reasoning, it also highlighted certain **limitations of linear token streams** - particularly for spatially complex puzzles that involve:

- Irregular patterns (e.g., diagonals or nested structures),
- Spatial relationships not easily expressed sequentially,
- Color-based grouping logic requiring 2D adjacency awareness.

To address these limitations, we propose a future enhancement to the ARC-AGI reasoning pipeline: the introduction of **perceptual tokens** and/or **hybrid architectures** that combine symbolic reasoning with spatial perception.

Perceptual Tokens

These would encode higher-level visual or semantic properties extracted from the grid, such as:

- Connected components,
- Symmetry types,
- Object counts,
- Bounding boxes,
- Shape descriptors.

By introducing tokens like <centered>, <horizontal-line>, or <enclosed-area>, the LLM could reason more explicitly over visual concepts rather than inferring them indirectly from raw pixel values.

Hybrid Architecture

A complementary approach involves fusing:

- **A lightweight visual frontend**, such as a CNN or ViT, to extract structured features from the grid, with
- **A symbolic backend**, like a language model, for rule-based inference and pattern completion.

Such a system could resemble a **neuro-symbolic model** where perception and reasoning are decoupled but interactively aligned - allowing each module to excel at its specialty. The ultimate goal of ARC-AGI is to model abstract human-like reasoning. Humans solve visual puzzles by first *perceiving* objects and relationships, then *reasoning* about them symbolically. By augmenting LLMs with even shallow perception modules or semantically enriched tokens, we could push their abstraction capabilities closer to true AGI behaviour.

Error Analysis

In addition to our primary symbolic-neural approach, we also evaluated a convolutional segmentation model **U-Net** — trained on the ARC dataset using image-based representations. We applied data augmentations from RE-ARC and rendered the symbolic JSON grid tasks. While the model reported a seemingly high pixel-wise accuracy of **99%**, the outputs were incorrect and misleading, representing classic **false positives**. The U-Net model failed to understand the task logic and instead overfit to visual patterns — especially the dominant blank-space background present in most ARC grids. As shown in the outputs below, the predicted results did not reflect the required grid transformations. Instead, the model often reproduced near-identical background visuals, which inflated pixel-accuracy scores without solving the actual problem.

This failure occurred because converting structured JSON grids into flat images strips away their semantic and hierarchical meaning. U-Net could only learn superficial cues like edges or blankness, rather than abstract rules or relational patterns. Consequently, the model memorized trivial visual traits and produced outputs that appeared accurate numerically (pixel-wise), but semantically they were incorrect.

In summary, this experiment highlights the limitations of applying pixel-based CNN architectures to symbolic tasks like ARC. It reinforces the importance of preserving task structure through symbolic tokenization and the need for reasoning-based models over perceptual ones in few-shot abstraction tasks.

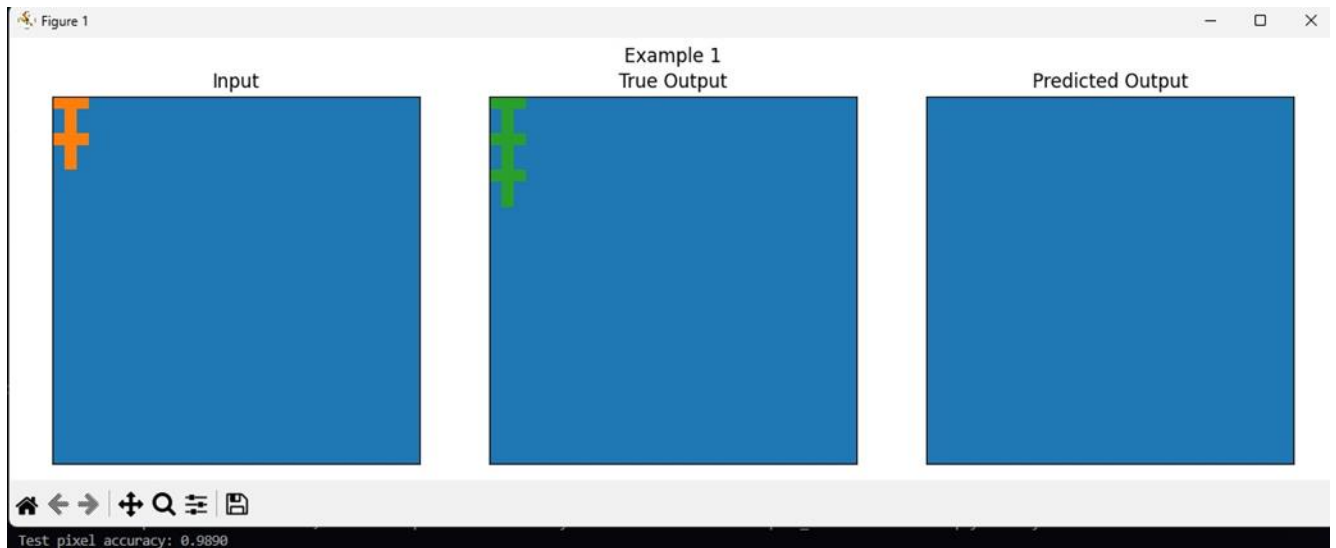
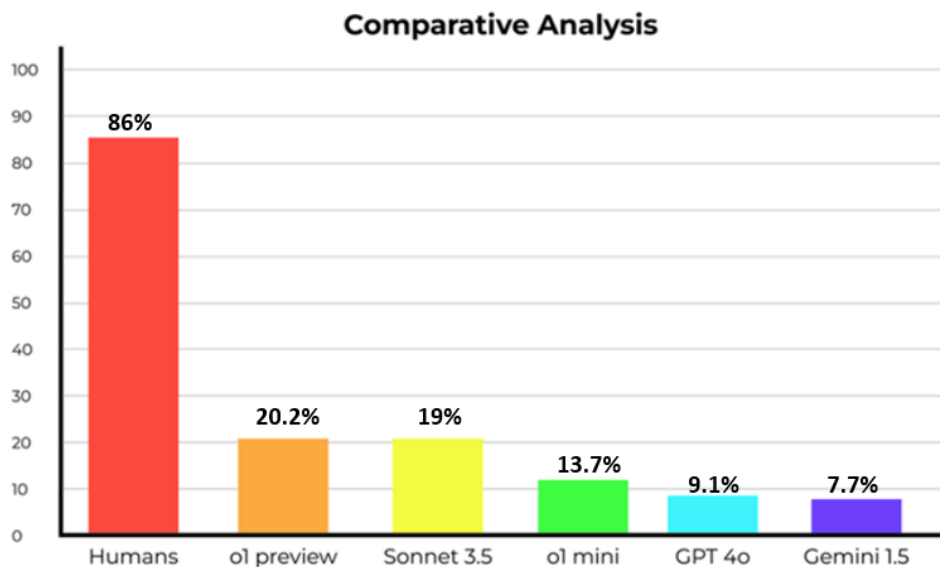


Figure 8: Error noticed after using U-NET

The approach failed because rendering JSON as images strips away its hierarchical and semantic structure, leaving U-Net to pick up only superficial pixel patterns—chiefly edges and background - rather than the underlying data relationships. As a result, the model essentially memorized and copied the dominant blank-space background, inflating pixel-level accuracy to 99% without truly learning JSON grammar. Moreover, using raw pixel-accuracy on near-uniform images is misleading: it rewards trivial identity mapping and ignores whether the actual JSON content is correctly reconstructed. In short, treating symbolic data as images led to overfitting on visual artifacts instead of genuine understanding.

Comparative Analysis



This figure shows a comparative analysis chart that illustrates the performance of various AI models on the ARC (Abstraction and Reasoning Corpus) benchmark. Humans demonstrate a significantly higher accuracy, scoring above 85%, highlighting the complexity of ARC tasks and the gap in current AI capabilities. Among the models tested, o1 preview and Sonnet 3.5 perform similarly, achieving around 20%, while lighter models like o1 mini, GPT-4o, and Gemini 1.5 score below 15%. This visual comparison emphasizes that even the most advanced LLMs still struggle with symbolic reasoning, abstraction, and generalization when compared to human cognition—reinforcing the ARC challenge as a true test of AGI potential.

Table : Comparing the two approaches

Aspect	DSL + Genetic Algorithm	LLM + Tokenization & Augmentation + DFS
Core Idea	Solve ARC tasks using a custom DSL	Use fine-tuned LLMs to generate grid completions via sampling
Methodology	Enumerate DSL programs via a genetic algorithm - Optimize for grid-to-grid IO mappings	- Convert grids to compact token format - Fine-tune LLMs with data + augmentations - Use DFS sampling to generate completions
Representation	Uses a custom-designed DSL with ~ 11 parameters	Uses 64-token vocabulary and direct grid-to-text conversion
Search Strategy	Genetic search: based on fitness	DFS sampling guided by LLM probabilities
Generalization	Generalizes symbolically through primitives	Generalizes statistically across similar pattern distributions
Augmentation	None used explicitly	Extensive augmentations (symmetry, color, input shuffling)
Computation Time	Relatively slow due to program enumeration	Efficient inference due to LLM decoding
Data Dependency	Can work with small datasets	Relies heavily on pretraining with large synthetic corpora
Limitations	Requires strong priors on DSL design Brute Force technique	Doesn't "understand" tasks; relies on memorization & augmentation Sensitive to tokenization

Conclusion

In this research, we set out to explore whether large language models (LLMs) possess true abstract reasoning abilities or simply mimic such behavior through memorized patterns and brute-force augmentation. By designing and implementing two complementary approaches—a symbolic DSL-based genetic algorithm and a fine-tuned LLM pipeline with structured augmentations—we were able to probe this question from both ends of the symbolic-to-neural spectrum.

What we found confirms a central insight: **LLMs today are more memory than mystery**. While our LLM pipeline, equipped with careful data representation, augmentation, and sampling, achieved promising results on ARC-AGI tasks, the reasoning it demonstrated was largely emergent

from engineered representations, not innate generalization. The success of these models hinged not on spontaneous intelligence, but on how cleverly we fed the problem to them.

ARC, by design, resists memorization-based approaches. Yet we observed that LLMs could still solve many tasks—not because they "understood" in the human sense, but because our preprocessing enabled them to exploit symbolic patterns. Even subtle changes in formatting or tokenization significantly altered outcomes, which is a clear indicator that the model's success was dependent on surface-level pattern recognition, not deep abstraction.

Our findings reinforce Chollet's assertion that true intelligence lies in the ability to generalize from minimal examples, a quality that current LLMs lack. They excel at interpolation within known distributions but falter in extrapolating new concepts. In the context of ARC, this means that their performance is tightly bound to the diversity of augmentations and the token-level tricks we applied—not to a genuine understanding of the underlying task.

Despite these limitations, we believe our work advances the frontier by showing how symbolic and neural components can complement each other. While LLMs alone are not yet AGI, when scaffolded with task-specific augmentations, token-level encoding, and structured search, they begin to exhibit behaviors that edge closer to generalization. The mystery, then, is not within the models themselves, but in the human ingenuity used to push their boundaries.

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