Level Generation with Constrained Expressive Range

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Motivation

- **Expressive Range** plots two metrics to visualize content distribution in 2d space.
- We use the expressive range of a generator as the **conceptual space of possible creations.**
- Inspired by the **quality diversity paradigm**, we explore this space to generate levels.
- Unlike typical quality diversity approaches that rely on **random** generation, this approach **systematically** traverses the grid ensuring more **coverage**.

- Smith, Gillian, and Jim Whitehead. "Analyzing the expressive range of a level generator." Proceedings of the 2010 workshop on procedural content generation in games. 2010.
- Daniele Gravina, Ahmed Khalifa, Antonios Liapis, Julian Togelius, and Georgios N.Yannakakis. 2019. Procedural Content Generation through Quality Diversity. 2019 IEEE Conference on Games (CoG) (2019), 1–8.

Previous Work

- During the development of the game That's Me TV, **Guzdial et al.** used expressive range visualization to adjust the game's mechanics until they matched his design goals.

- **Madkour et al.** used expressive range as a way for designers to directly interact with their probabilistic graph grammar system, allowing them to define their desired generative space by selecting a region on a plot.

- Guzdial, Matthew, et al. "Tabletop roleplaying games as procedural content generators." Proceedings of the 15th International Conference on the Foundations of Digital Games. 2020.
- Madkour, Abdelrahman, Stacy Marsella, and Casper Harteveld. "Towards non-technical designer control over PCG systems: Investigating an example-based mechanism for controlling graph grammars." Proceedings of the Foundations of Digital Games. 2022.

Metric Pair Selection

Smith and Whitehead used metrics like **linearity**, **leniency**, and **density** to assess the variety and tendencies of generated levels.

Later work, such as Withington and Tokarchuk, emphasized the importance of choosing more **contextually relevant metrics** to better capture variations in generated content.

Density: the number of tiles in a segment that aren't background tiles.

Difficulty: the number of tiles of a segment that are occupied by any enemy or are hazard tiles (including gaps).

- Smith, Gillian, and Jim Whitehead. "Analyzing the expressive range of a level generator." Proceedings of the 2010 workshop on procedural content generation in games. 2010.
- Withington, Oliver, and Laurissa Tokarchuk. "The right variety: Improving expressive range analysis with metric selection methods." Proceedings of the 18th International Conference on the Foundations of Digital Games. 2023.

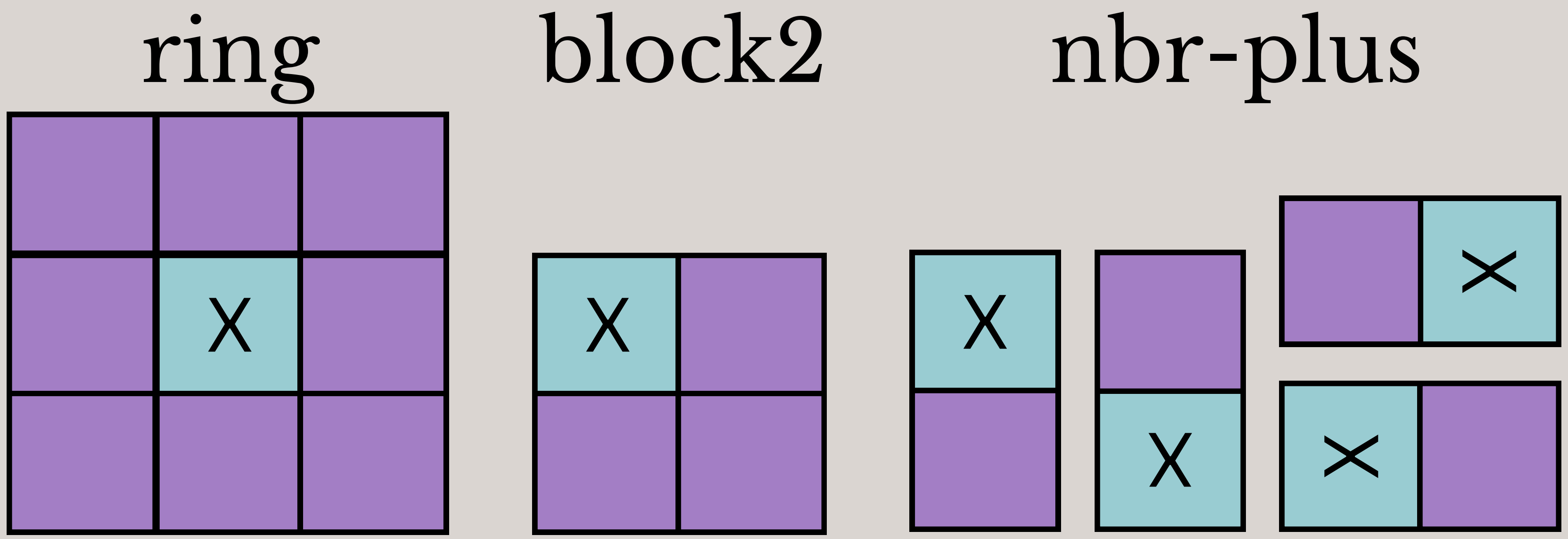
Constraint-Based Generation

- In this work, we use the Sturgeon constraint-based level generator.
- Sturgeon leverages a mid-level API to define constraints on Boolean variables, which it translates into low-level constraint satisfaction problems.
- As a result, Sturgeon ensures that the generated levels meet the specified constraints precisely, without any errors or noise.
- Sturgeon can impose constraints on overall tile counts that we utilized to enforce specific metric values.
- This is straightforward for both density and difficulty metrics.

- Seth Cooper. 2022. Sturgeon: tile-based procedural level generation via learned and designed constraints. In Proceedings of the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment, Vol. 18. 26–36.

Pattern Templates

- Sturgeon enforces local tile constraints to replicate example level structures.
- It uses pattern templates to guide thus tile arrangement instead of random placement.
- Templates define input-output patterns, restricting valid tile transitions.



- Seth Cooper. 2022. Sturgeon: tile-based procedural level generation via learned and designed constraints. In Proceedings of the AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment, Vol. 18. 26–36.

Exploring the Expressive Range Space

- The exploration process uses a prioritized random selection.
- Underrepresented cells have fewer than 10 levels are prioritized.
- These cells are randomly selected.
- They can be chosen multiple times until reaching the threshold.
- Failed or full cells are blocklisted to prevent deadlock.
- We use a fixed time limit for each pattern template to explore the expressive range.
- We use timeout to prevent solvers from getting stuck on more challenging density-difficulty settings.

Exploring the Expressive Range Space

- This approach somewhat reverses the typical quality diversity search.
- Instead of hoping for coverage, it systematically explores the space.
- We also test the generator without constraints, allowing **random** level creation. (**imitating quality diversity**)
- We compare how well these random levels cover the space.
- To assess the **quality** of the generated levels, we use a quantitative measure of **interestingness**.

Interestingness

Interestingness = Path length + Number of jumps

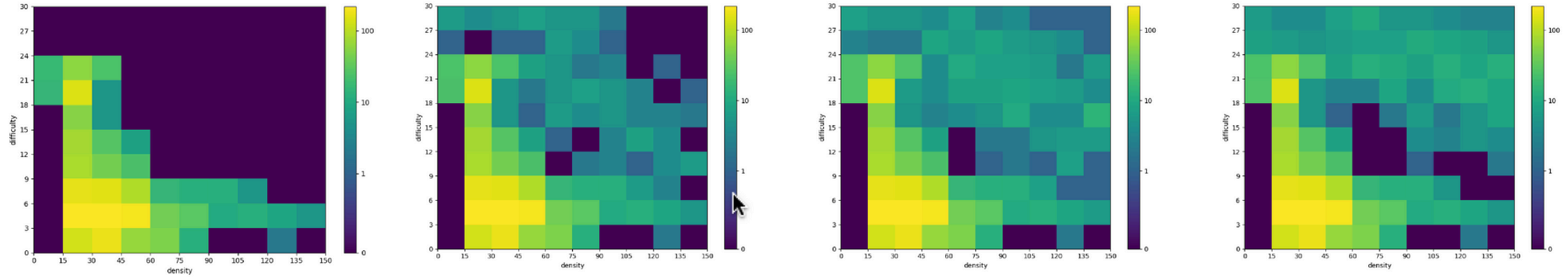
Path length (which reflects gameplay duration)
Number of jumps (which reflects the player's engagement).

- This quantitative measure is inspired by gameplay features detected in previous works, that significantly correlate to being **fun**.
- The definition of interestingness is **not** a definitive measure of the quality of the generated levels
- It provides insight into which levels are engaging and playable, rather than bland or unplayable.

- Pedersen, Chris, Julian Togelius, and Georgios N. Yannakakis. "Modeling player experience in super mario bros." 2009 IEEE Symposium on Computational Intelligence and Games. IEEE, 2009.

Systematic Exploration

- Different template patterns demonstrated differing performances in exploring the expressive range of games.
- The ring pattern, due to its more restrictive constraints, was less successful in covering all cells.
- As the patterns relaxed these constraints, their ability to find level solutions for each cell improved.



(a) *initial corpus* (b) *extended corpus - ring* (c) *extended corpus - block2* (d) *extended corpus - nbr-plus*

Figure 3: Density-difficulty expressive range of expanded corpus with each pattern template. The color bar is based on SymLogNorm allowing linear behavior around zero and logarithmic beyond.

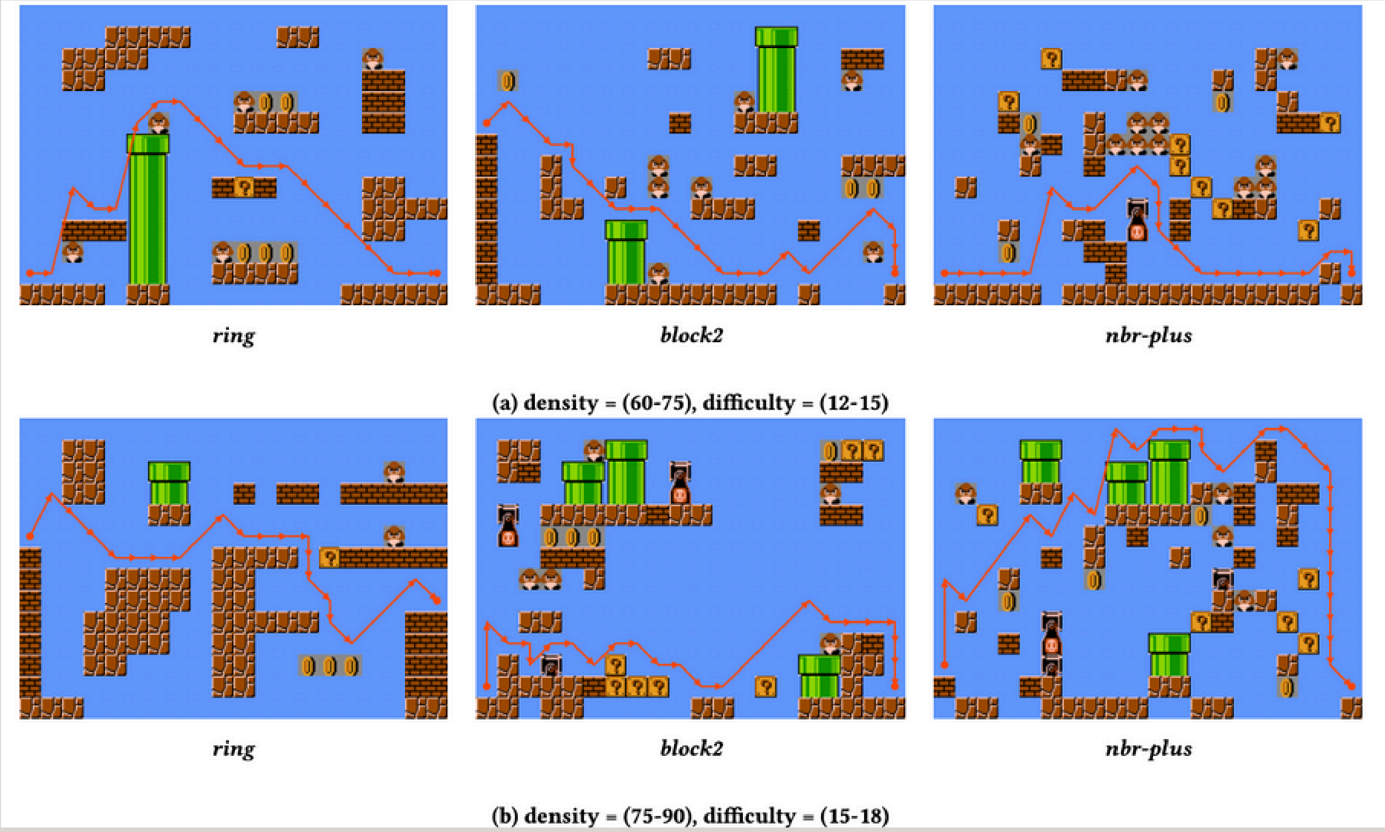
Systematic Exploration

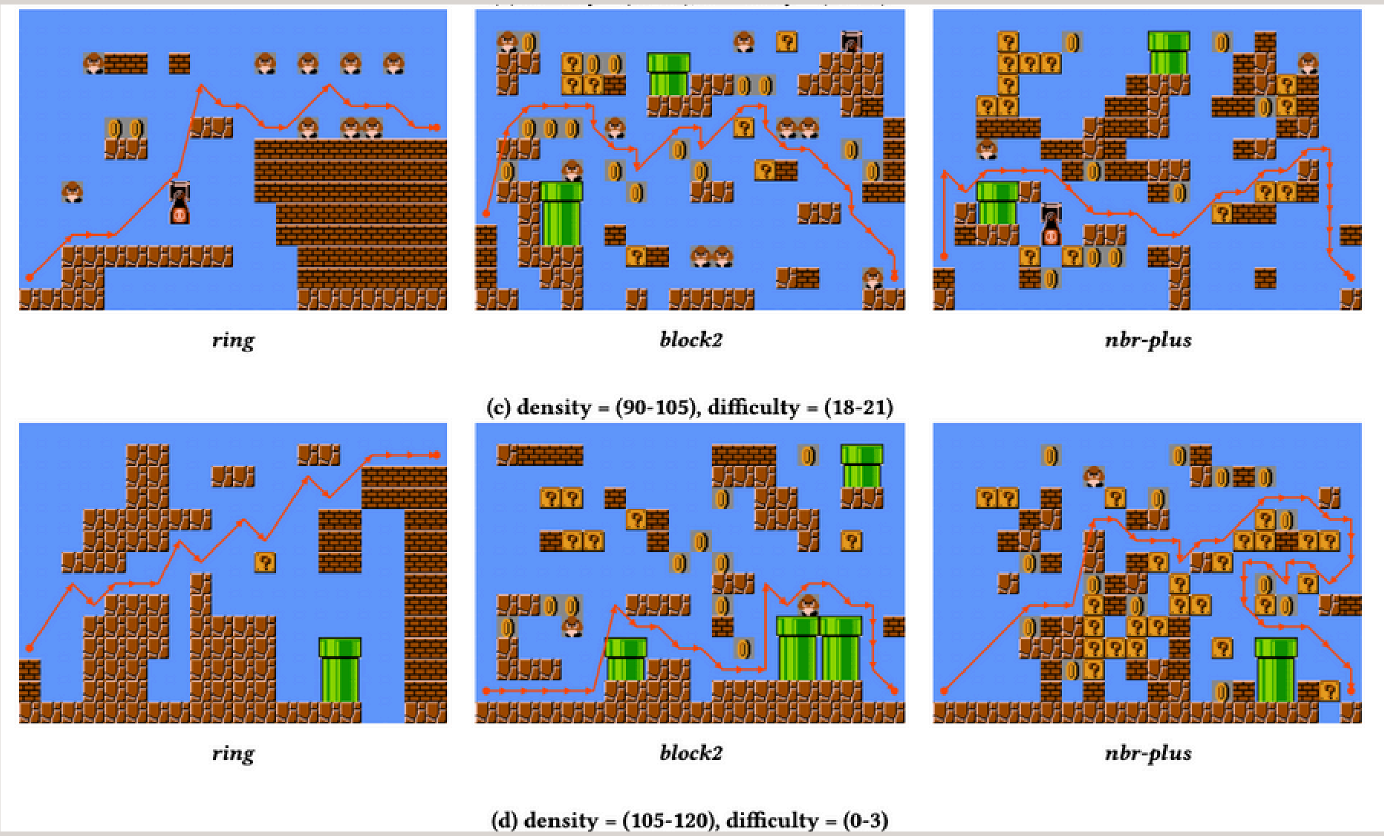
Less-constrained pattern templates are faster at finding solutions.

There is a trade-off between maintaining an ideal structure and optimizing speed.

Pattern Template	Total Attempts	Successful Attempts	Failed Attempts	Timed Out Attempts	Average Solve Time (s)	Average Fail Time (s)	Average Time (s)
ring	200	177	2	21	150.09	73.73	374.61
block2	294	282	2	10	8.36	19.97	309.44
nbr-plus	315	313	2	0	0.98	30.78	10.57

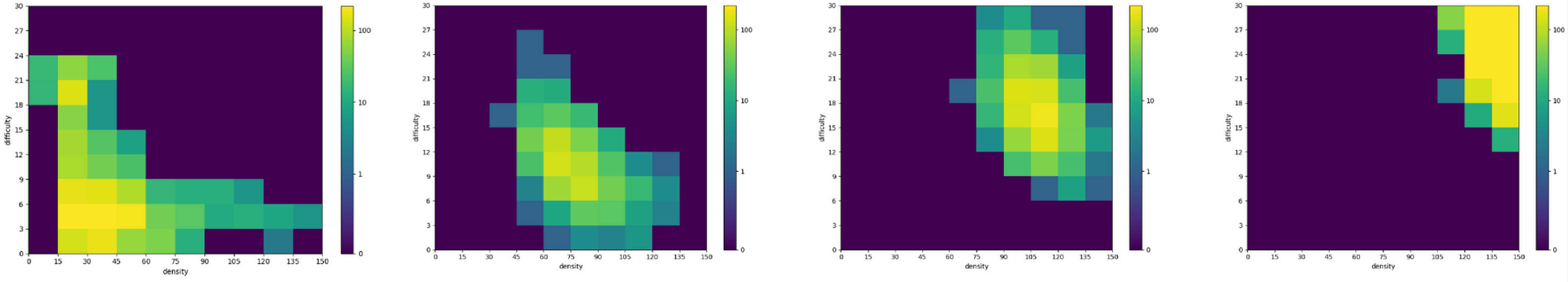
Table 1: Comparison of performance of different pattern templates in terms of successful attempts (resulted in level generation) within a fixed time limit.





Random Exploration

Random generation for each pattern template tends to cover entirely different areas of the expressive range.



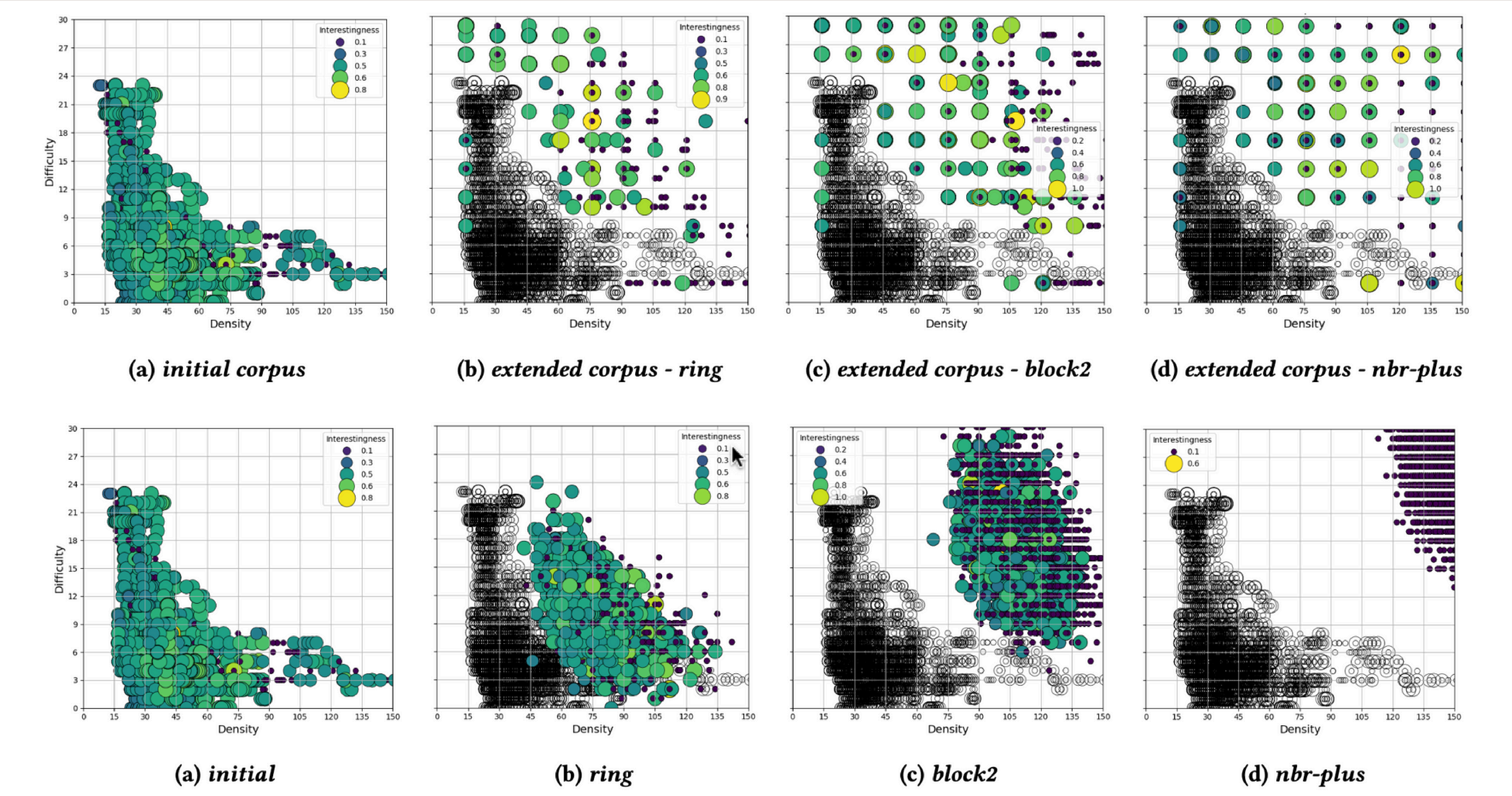
(a) ***initial*** (b) ***ring*** (c) ***block2*** (d) ***nbr-plus***

Figure 6: Density-difficulty expressive range of RANDOM generated corpus with each pattern template. The color bar is based on SymLogNorm allowing linear behavior around zero and logarithmic beyond.

Interestingness

Systematic Exploration

Random Exploration



Scatter plot displaying the interestingness of generated levels across the expressive range, with the size and color of each point reflecting its level of interestingness. uncolored points represent levels from the initial corpus in extended corpuses.

Conclusion & Future Work

- This work introduces a systematic method for Sturgeon to explore the expressive range in a controlled way.
- The approach is inspired by quality diversity but ensures full control over exploration.
- Future work will add more complex metrics that go beyond counting tiles and are harder to define as satisfaction problems for the generator (eg. linearity).

ThankYou!

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