# Using Novelty Search to Debug Physical Systems Simulations

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# Optimising Search

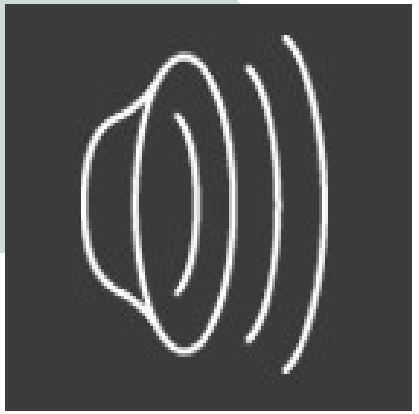
Optimising search finds an “optimal” solution to a problem

“Optimal” normally defined by some kind of metric

- Cost
- Score
- “How well does it do on this problem”

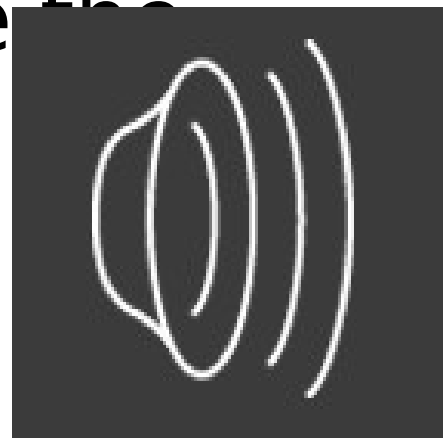
Lots of different methods

- Hill Climbing
- Simulated Annealing
- Genetic Algorithms



## Optimising Search – Bad?

- Standard problem: Local Optima vs Global Optima
- What if you don’t know what is optimal?
- Different solutions might solve different problems
- Multiple metrics might describe the quality of a solution



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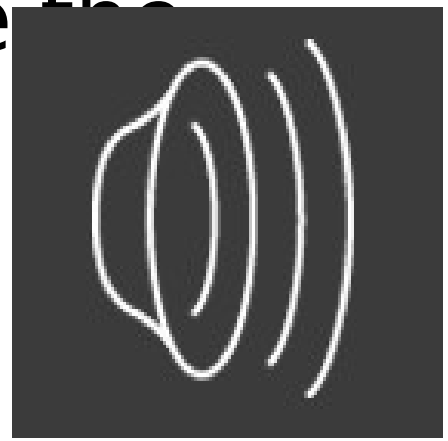

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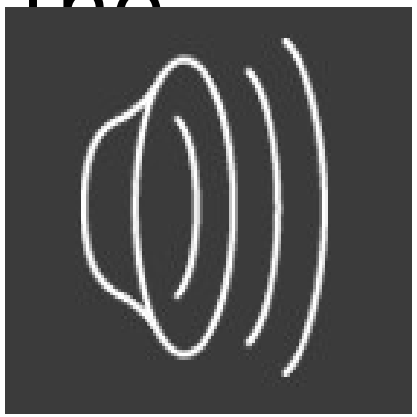
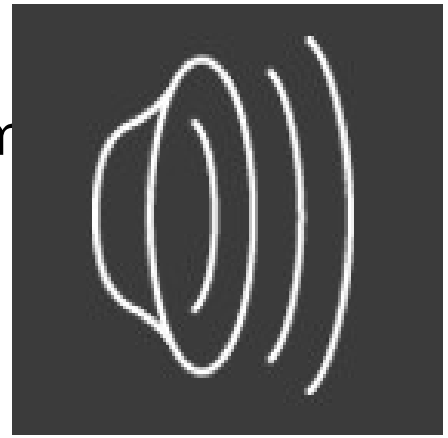


# Novelty Search

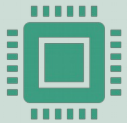
- Novelty Search is a partial solution to Optimising Search not being very good at some problems
- Defines a behaviour space given by metrics that describe behaviour of solutions
- Attempts to provide coverage of the behaviour space
- By covering the behaviour space, solutions with unusual or novel behaviours can be found
- Multiple methods are available to achieve this
  - This talk uses PyCHARC with a Microbial Genetic Algorithm
  - Which itself is a reworking of the CHARC fram



# Software Engineering: Debugging

Debugging is a common activity

Remove software bugs from a piece of software



Software Bugs arise during software development

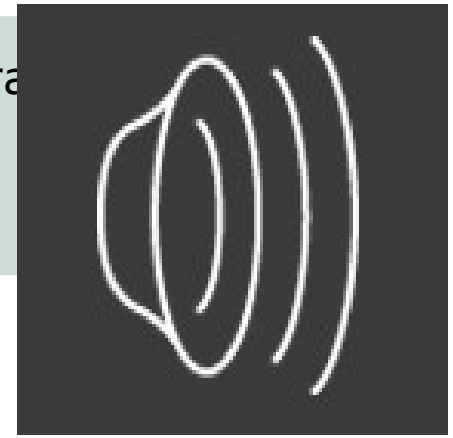
Typically defined as unintended, unexpected and incorrect behaviour

Software bugs can be found by a variety of approaches

Comparison against an ‘ora

Unit testing

Fuzzing



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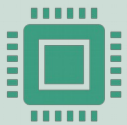

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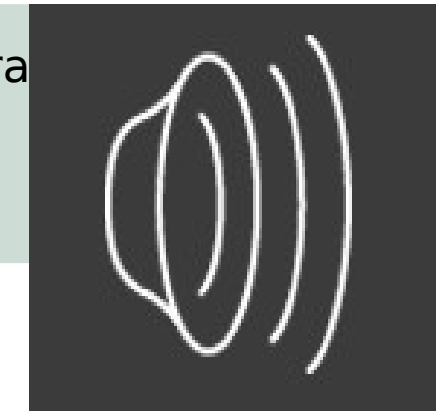

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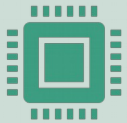

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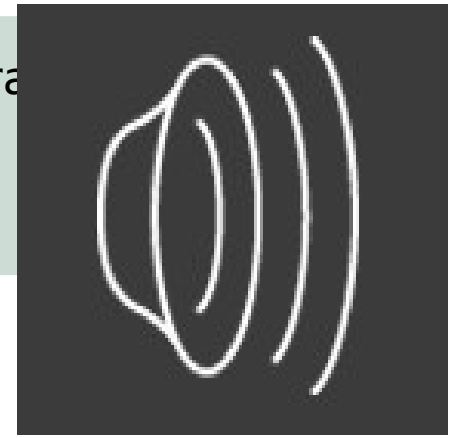
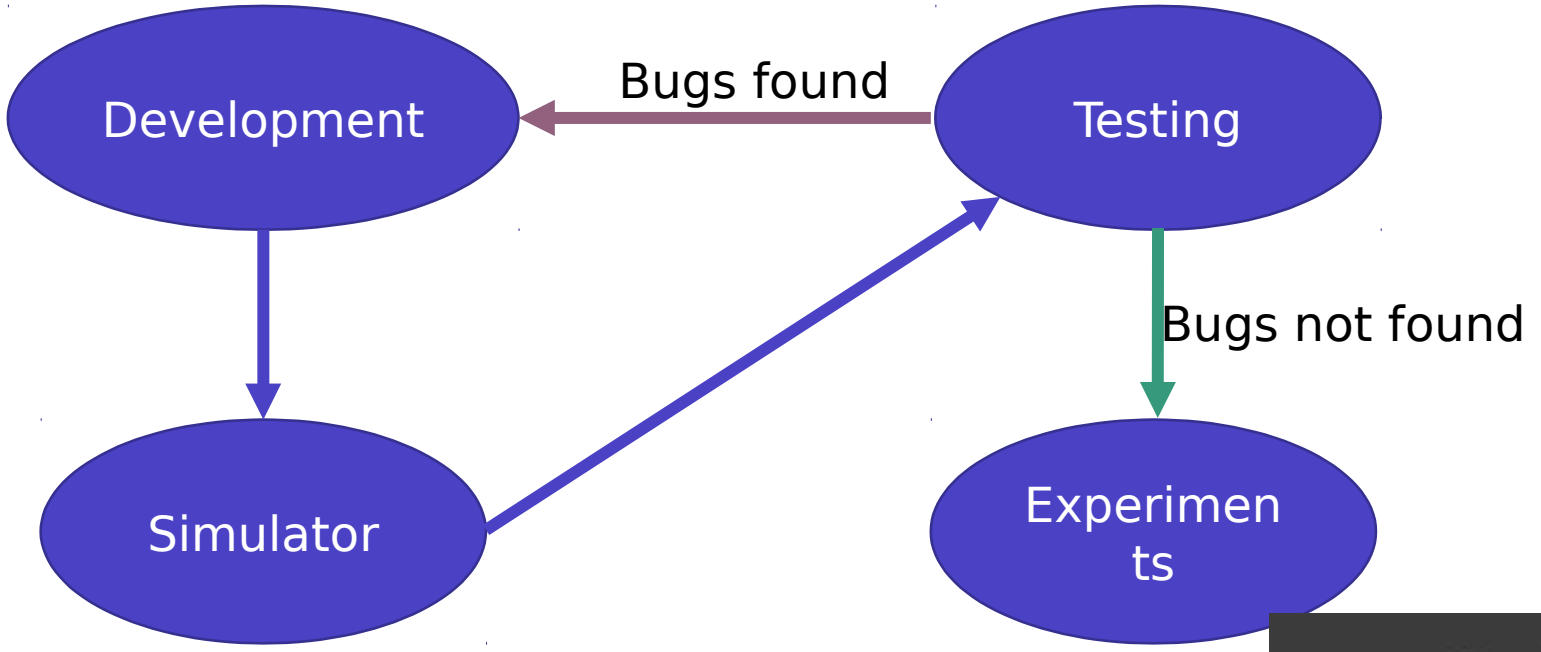


# Debug Workflow



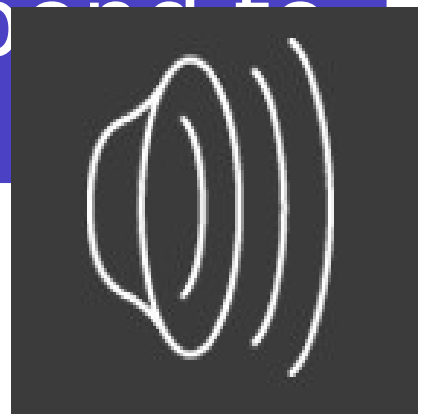
# Novel Behaviour = Bug?

Definitions from previous slides:

Software bugs and unintended, unexpected and incorrect behaviour

Novel behaviour is unexpected

Corollary: It is possible to use Novelty Search to find unexpected behaviours that may correspond to software bugs



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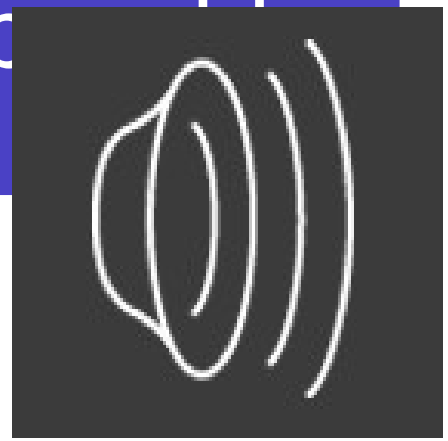
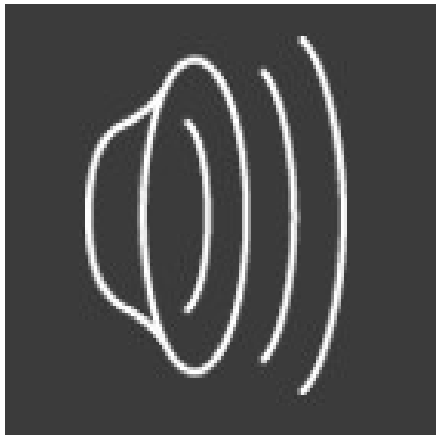


# DebugNS

- Application of Novelty Search to Debugging
- Replace Metrics with tests or testable hypotheses
- Novelty Search attempts to find where these tests or hypotheses yield the most “novel behaviours”
- If set up correctly, these novel behaviours correspond to either:
  - A bug in the software
  - A bug in the metric
  - Misunderstanding of what the system can do
- Advantage: If you’re already using Novelty Search to explore behaviours, it’s very easy to use it for debugging as well!



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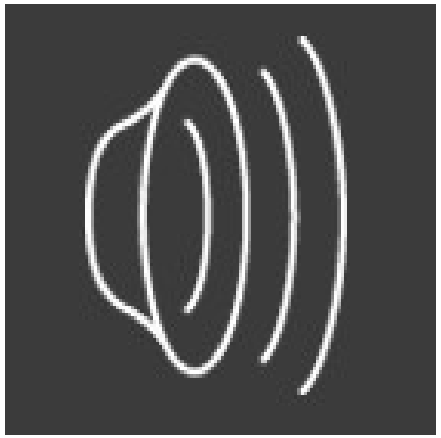

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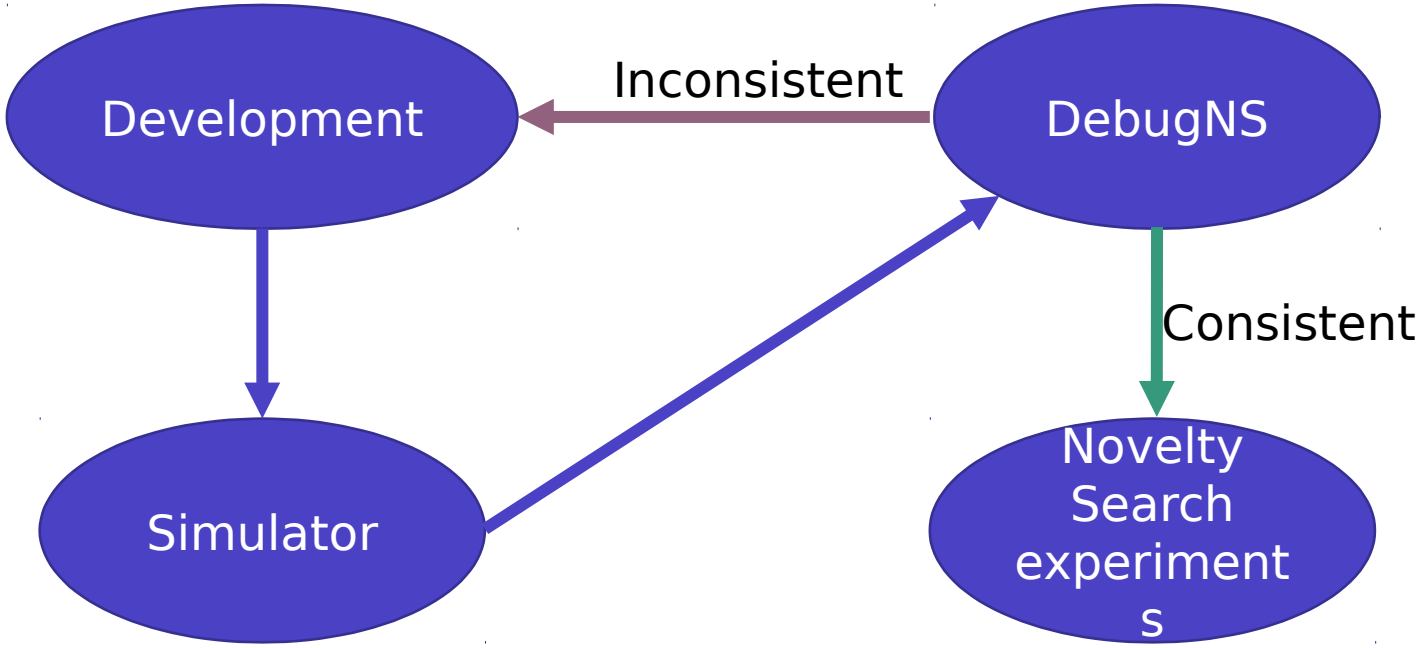

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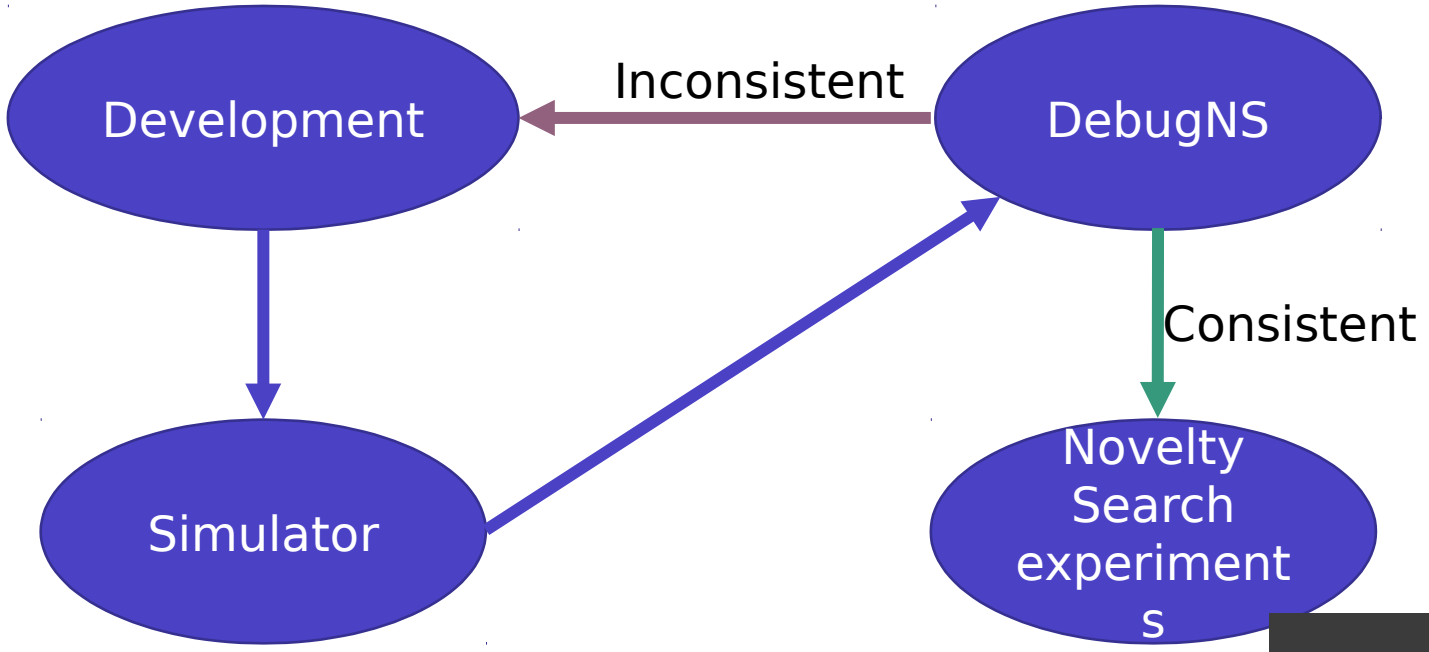


# DebugNS Metrics - Tests

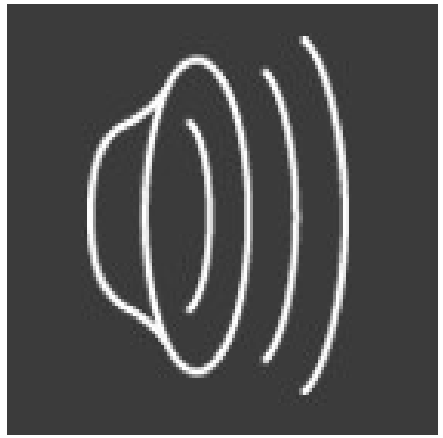
## Tests can be used for metrics

## DebugNS tests shouldn’t be binary

- Want to be more informative than ‘did it crash’ or ‘right answer’
- Can convert X < Y to two metrics: X, Y

## Criteria for a test are similar to normal unit tests

- Stress the system
- Try to exercise expected and corner cases



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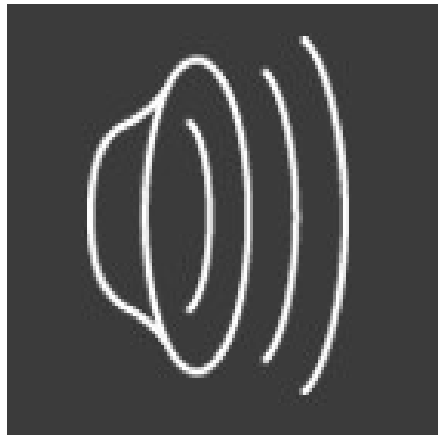


# DebugNS Metrics - Hypotheses

More abstract than using a test as a metric

Take outputs from system, evaluate it according to a hypothesis

- “No more than five types of output”
- “Output follows a known distribution”

Expose the underlying metrics to DebugNS

- Number of output types
- Multiple outputs from individuals

Easier to construct tests with a wider set of search over

- Can search over more of the behavior space

# DebugNS Metrics - Hypotheses

More abstract than using a test as a metric

Take outputs from system, evaluate it according to a hypothesis

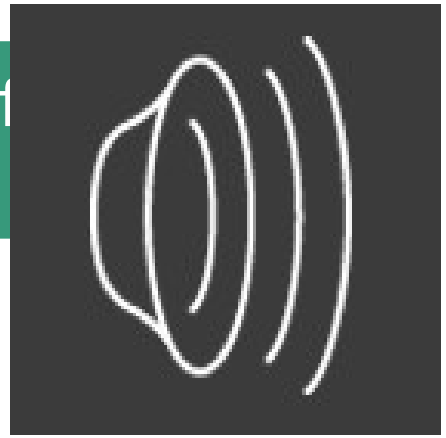
- “No more than five types of output”
- “No object travels faster than the speed of light”

Expose the underlying metrics to DebugNS

- Number of output types
- Speed of objects

Easier to construct tests with a wider set of search over

- Can search over more of the behavior space

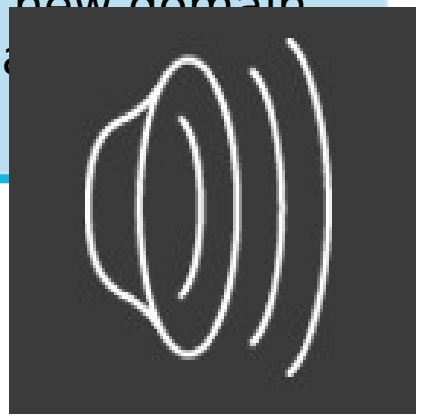


# Case Study: RingSim

RingSim is a simulator for nanoscale magnetic ring arrays (used for exploring possibilities with reservoir computing)

Simulates the progression of domain walls within the magnetic ring array

| | | | |
|---|---|---|---|
| Domain walls are moved around the rings by an external magnetic field | They can get pinned at junctions | They can annihilate if two opposite domain walls touch | They can spawn new domain wa |



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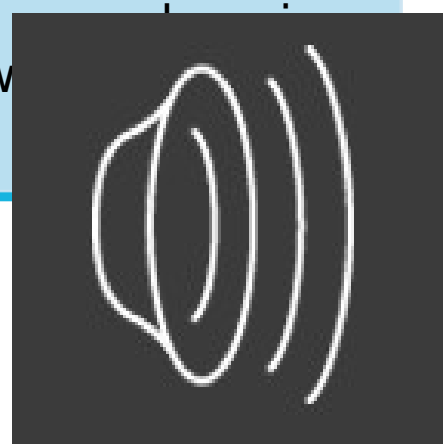

# RingSim v1 to v2

During development of RingSim there was a need to refactor the simulator

During this refactoring, DebugNS was used to examine RingSim for potential bugs

Experiments were carried out on a square grid arrays of varying size

- Graphs here use 5x5 for clarity

**RingSim DebugNS hypotheses**

| | |
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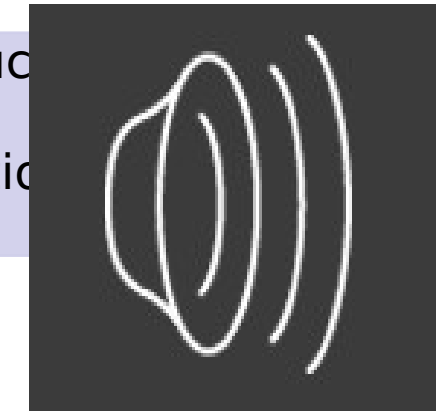
| Hypothesis | • behaviour of rings would fall into a class given by the local topography |
| Novelty Search Input | • Input magnetic fields to the ring array |
| Novelty Search Metric | • classes of each ring (determined by metrics from rings and clustering) |
| Expected behaviours | • Number of ring classes is muc than number of rings<br>• Ring class is mirror and rotatic symmetric |



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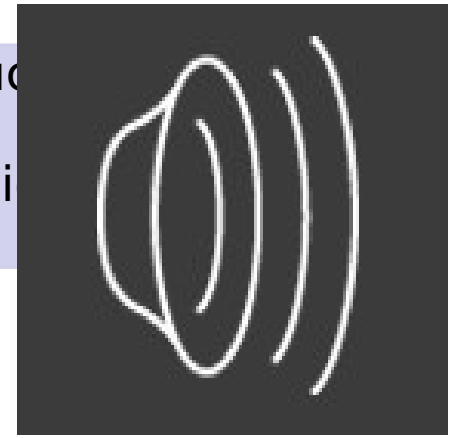
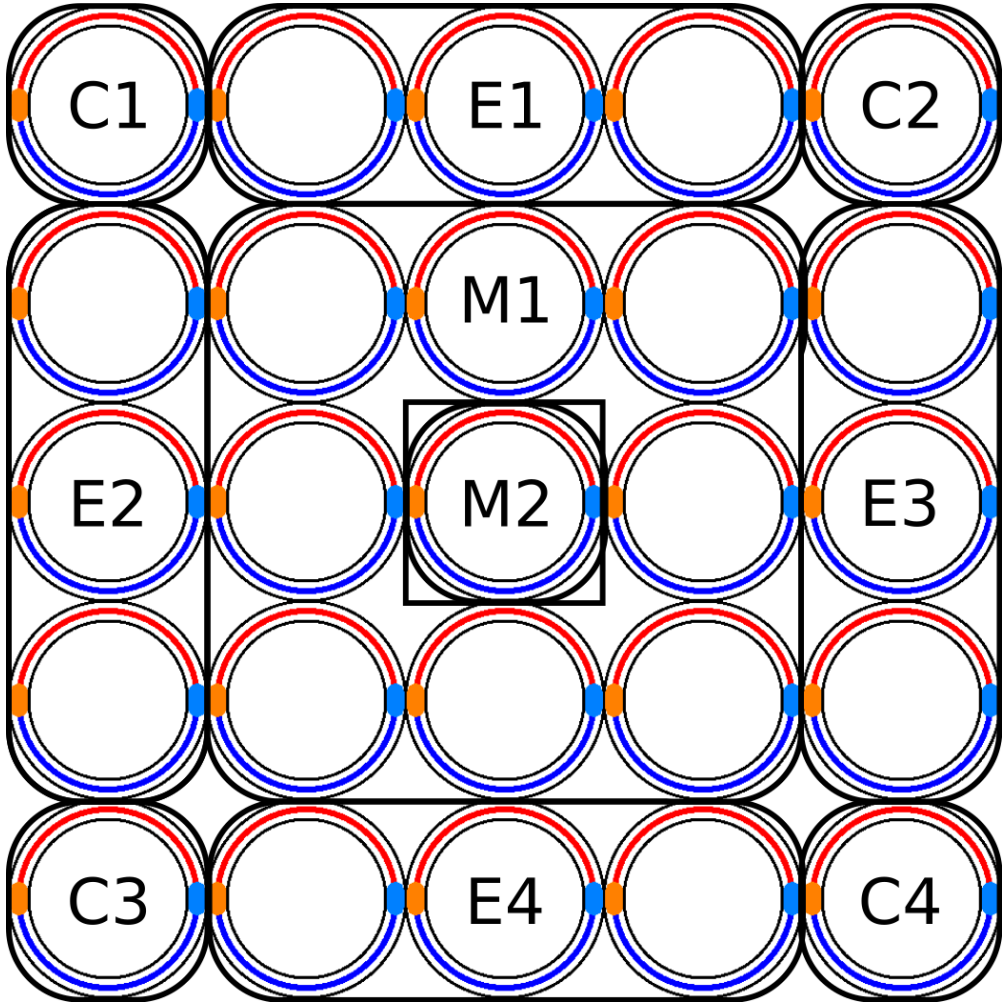


# Ring Classes in RingSim v1



# What happened?

Multiple bugs were found from the relatively simple hypotheses that were tested

- Domain walls could pass through each other rather than annihilating
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- Behaviour dependent on edge due to RingSim v1 updating rings sequentially

Observations were used to dev
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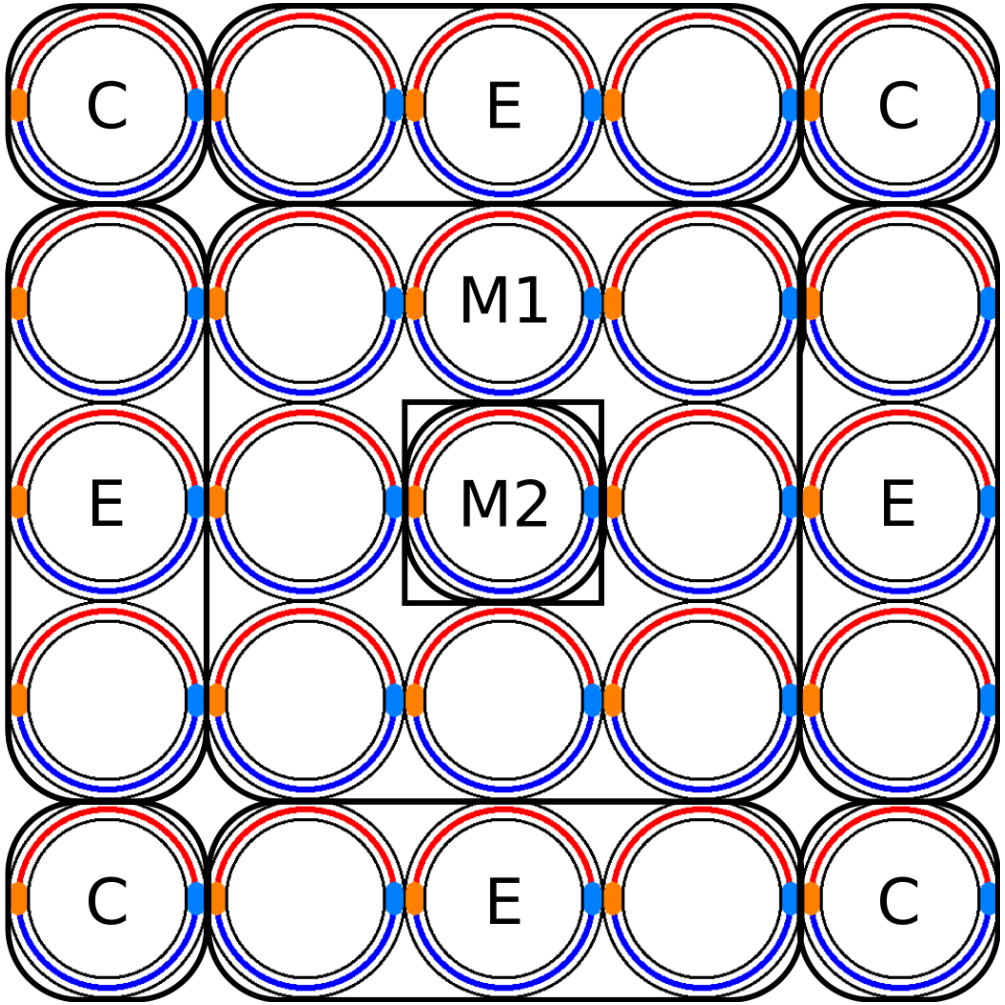

# Conclusions & Further Work

Novelty Search, with appropriate metrics, can be used as a debugging tool

And an easy-to-use debugging tool, if you're already planning on using Novelty Search

Potentially most powerful if there is a trusted oracle to compare results against – a slow but accurate simulator

But can also be used to get a population of varied individuals and check that a hypothesis holds

Future work: investigate using Novelty Search to automatically test equivalence between two systems

E.g. two implementations of an exp
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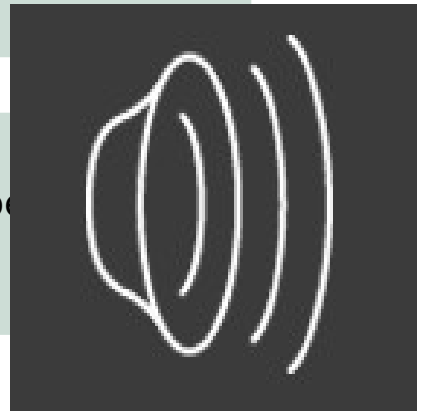

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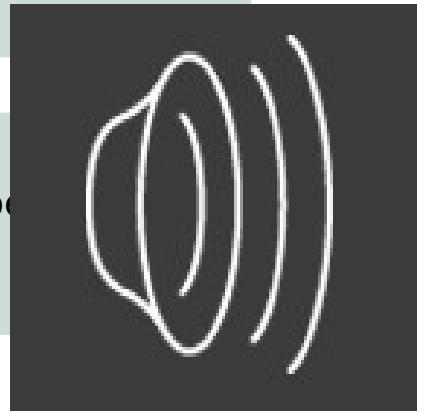

# Questions

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