Output Diversity

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Output Diversity

Why do we need output diversity?

How can we generate diverse outputs?

How effective is output diversity?

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What do we understand by diversity?

How the semantic information propagates to the output?

What's diversity

Low Similarity (Normalized Information Distance)

High **Entropy**

Entropy and diverse tests

We want a **generator** creating **diverse tests** for programs

The generator create tests sampling from a **maximum entropy** probability distribution

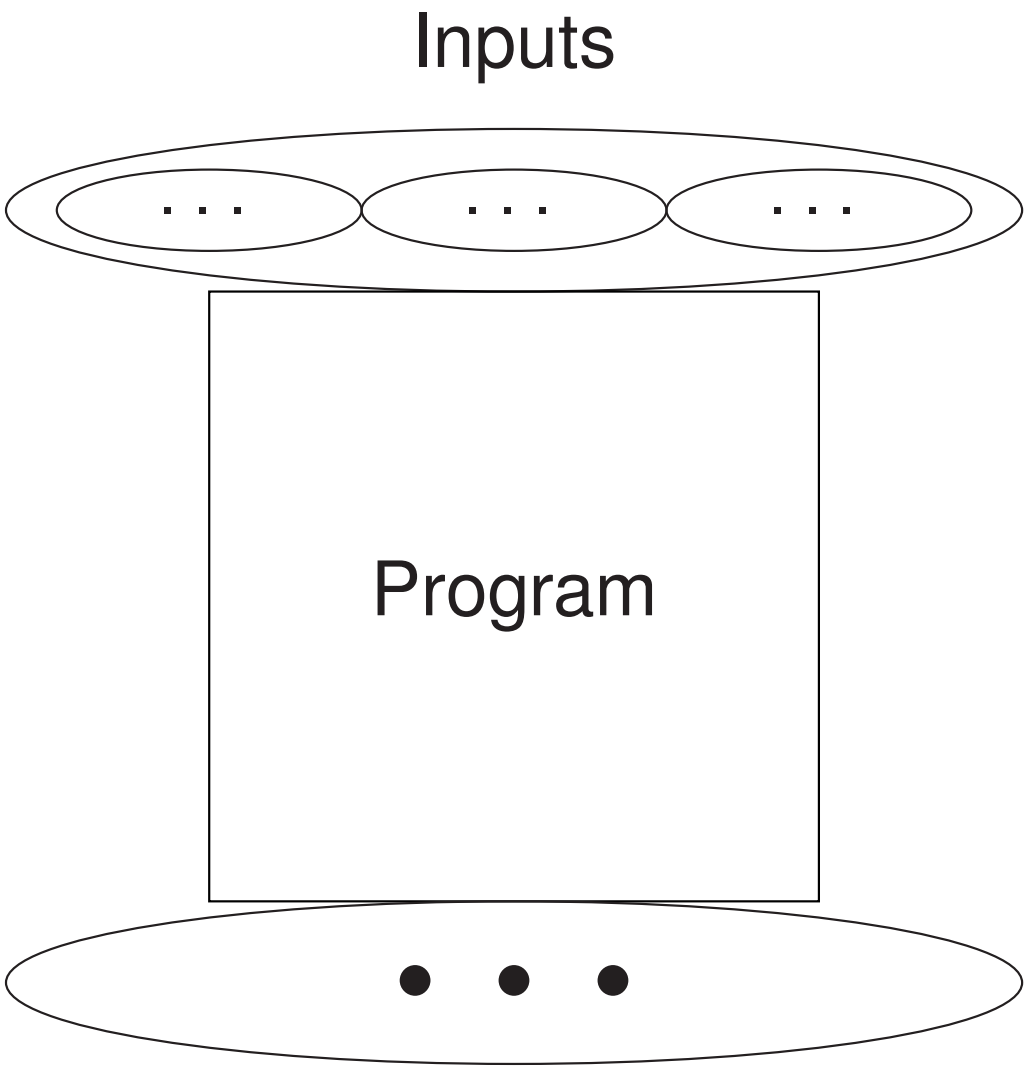
This probability distribution can only be a $\mathcal{U}$ **distribution**

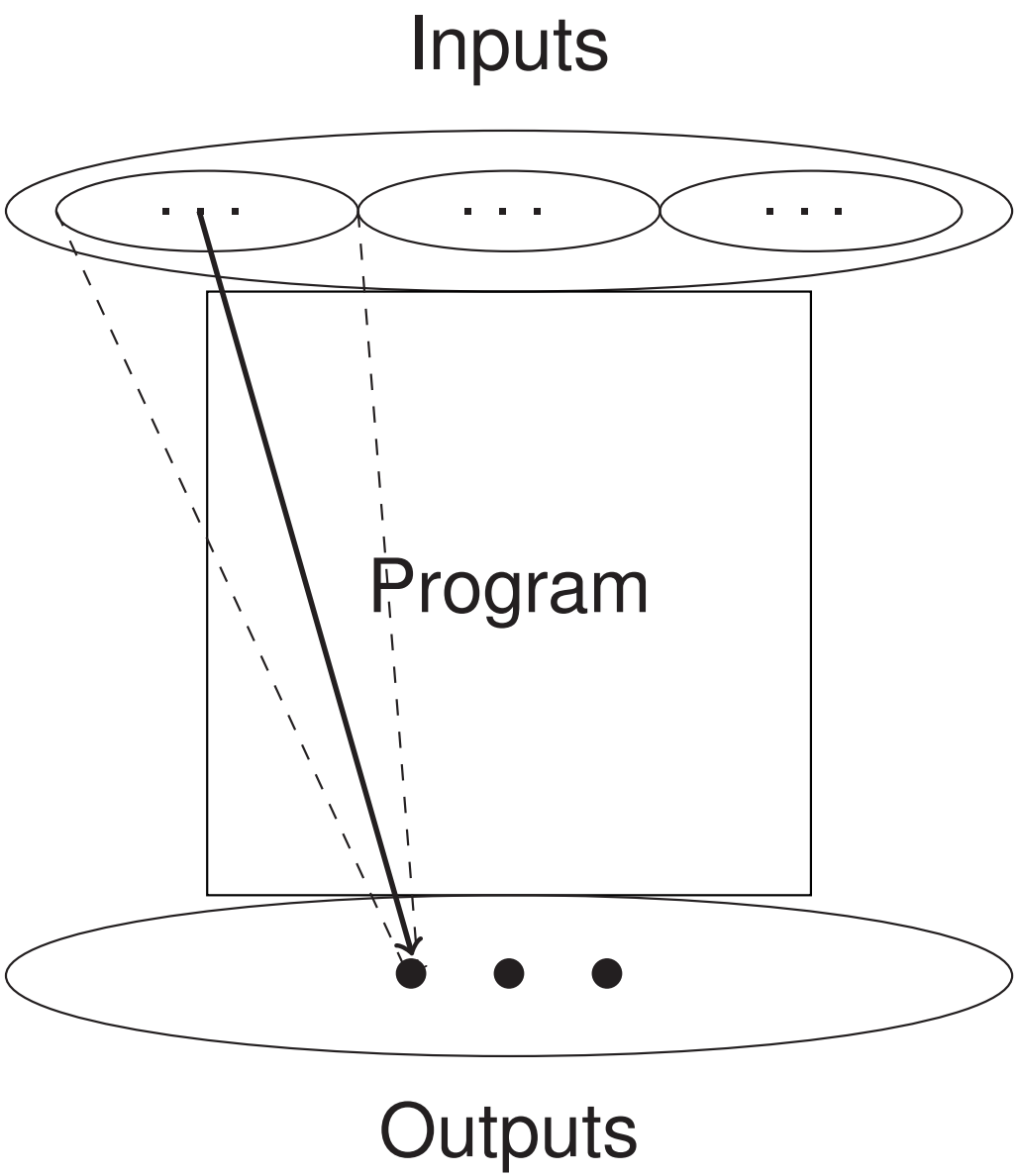
The output semantics

Considering deterministic programs, the I/O behavior works as a map.

The **squeeziness** directly affects to this map

We will need to balance **squeeziness** and **coverage**.


Inputs
Program
Outputs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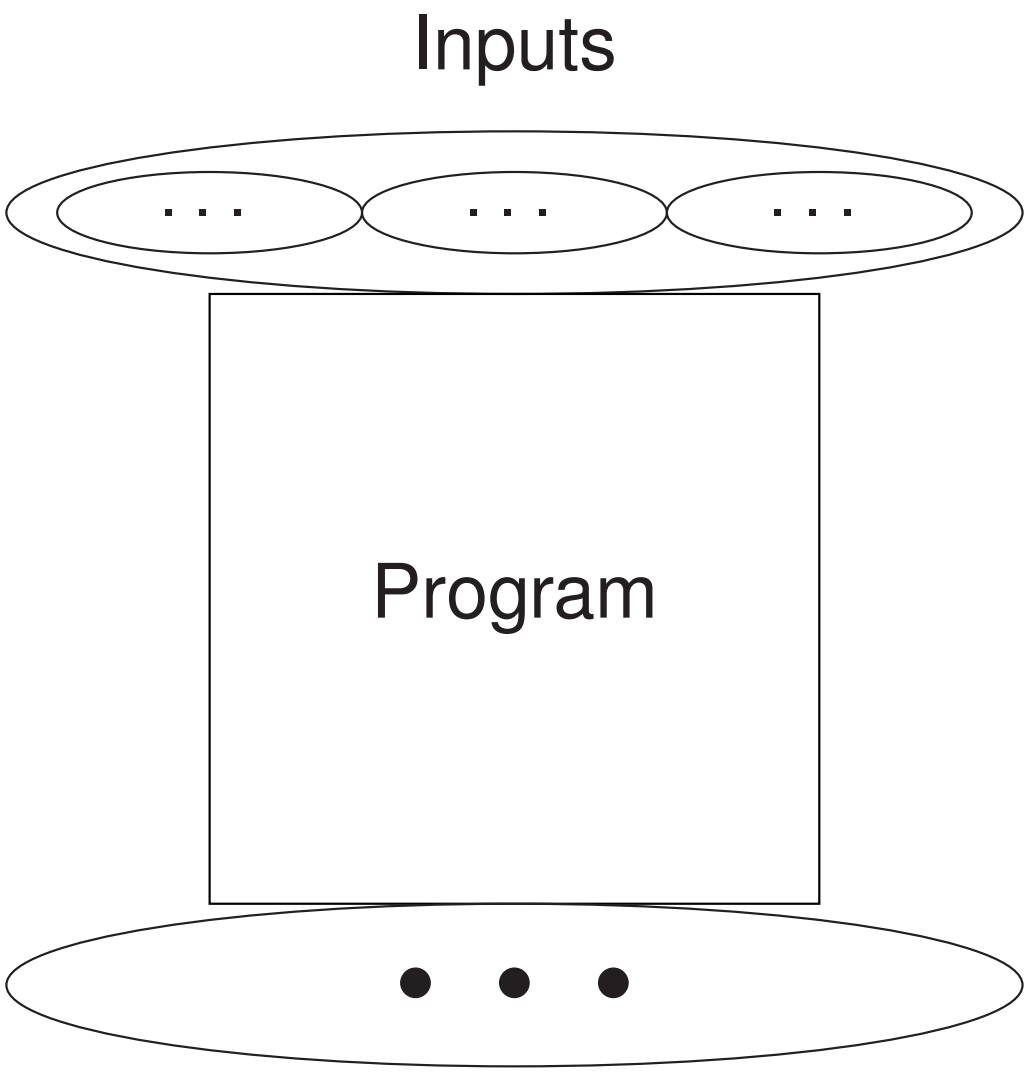
Inputs
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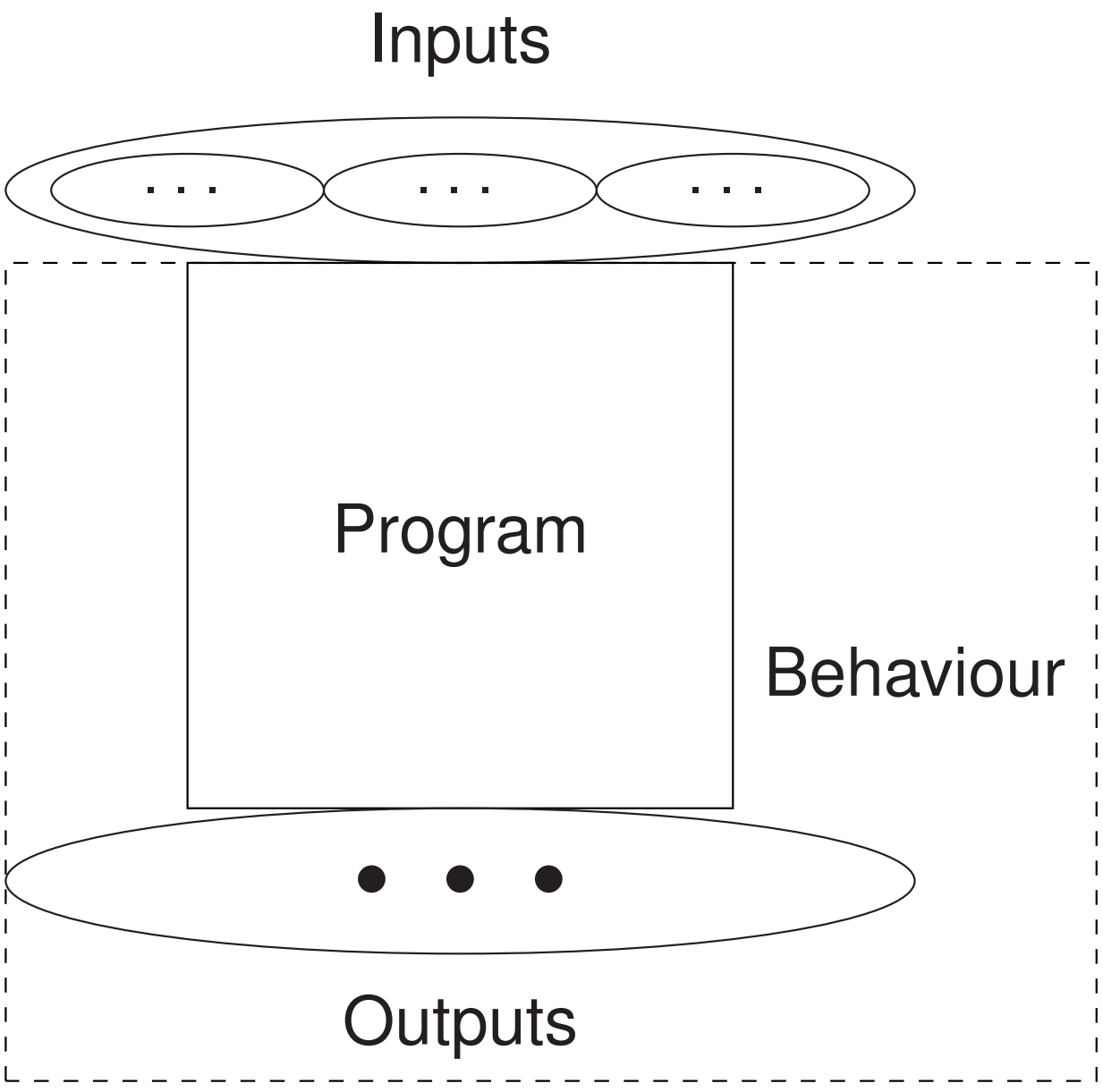
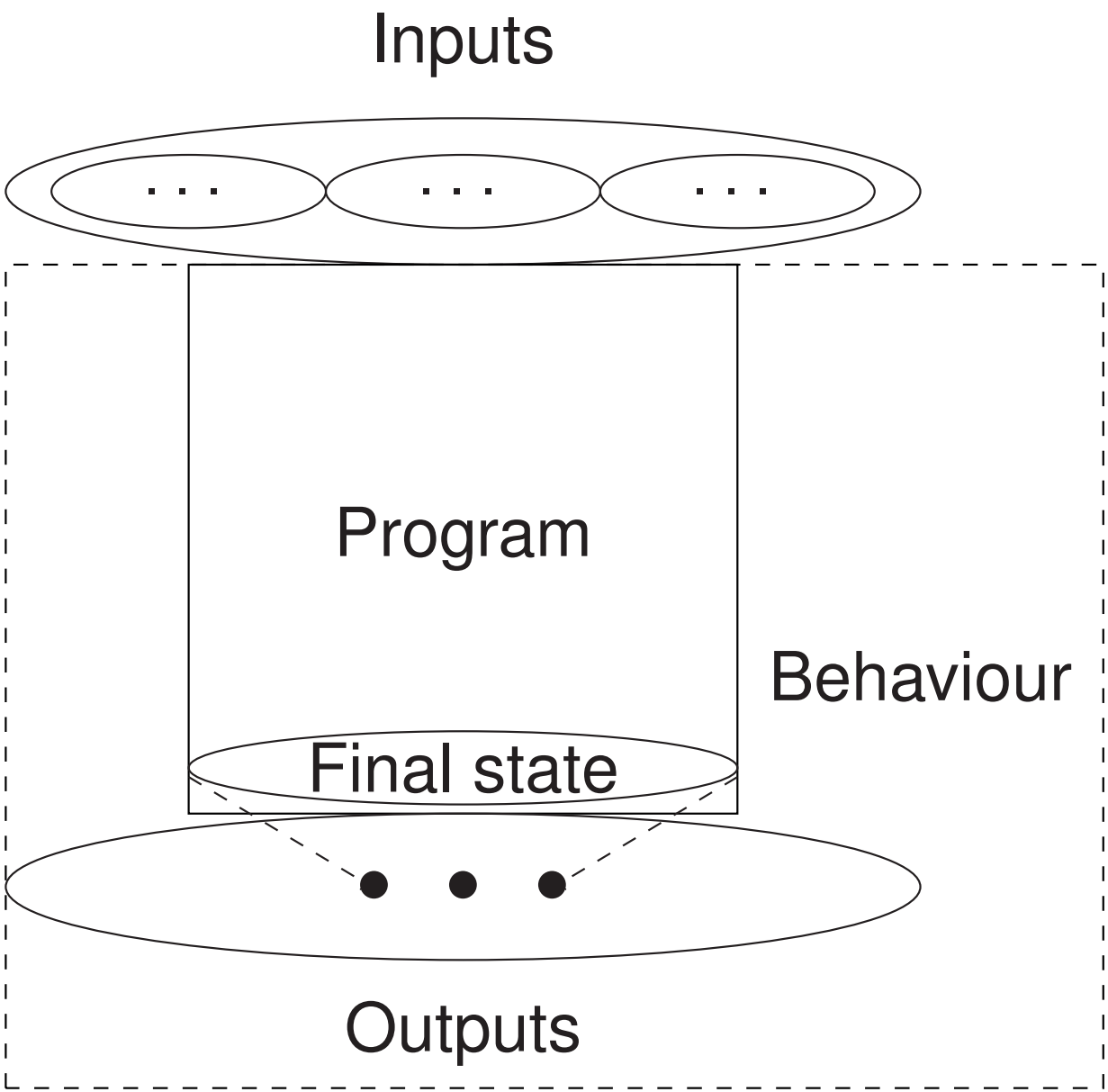

Inputs
Program
Behaviour
Outputs


Inputs
Program
Behaviour
Final state
Outputs

Output Diversity

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How effective is output diversity?

Output Diversity Approaches

Output-uniqueness: generate diverse inputs and filter by output uniqueness

Output-similarity: search for inputs improving a diversity metric based on similarity of outputs

What happens with the distribution?

Our goal is to maximize entropy, or create an **uniform distribution on the output set**

Roughly speaking, every output has the **same probability** to appear

The effect of the **squeeziness** attacks output uniqueness and search

The output diverse generator (I)

Chakraborty, Meel and Vardi created a diverse input generator based on **SAT solver**

The SUT is considered as a **formula** for a SAT solver (semantics)

They use the solver to create **inputs** through **witnesses** of this formula

The output diverse generator (II)

But the solver uses heuristics and it is **adversarial** in terms of uniformity

They improved uniformity through **universal hash functions**

They divide the inputs space into **cells** and select cells and witnesses uniformly at random

The output diverse generator (III)

We adapted this idea to the **outputs space**, keeping the ability of include extra information

We transform a **program** into a set of **constraints** and, using **bit-vector arithmetic**, we can also adapt their approach to **SMT solvers**

Outs Dom $d(P) \leqslant d(O)$ Proj

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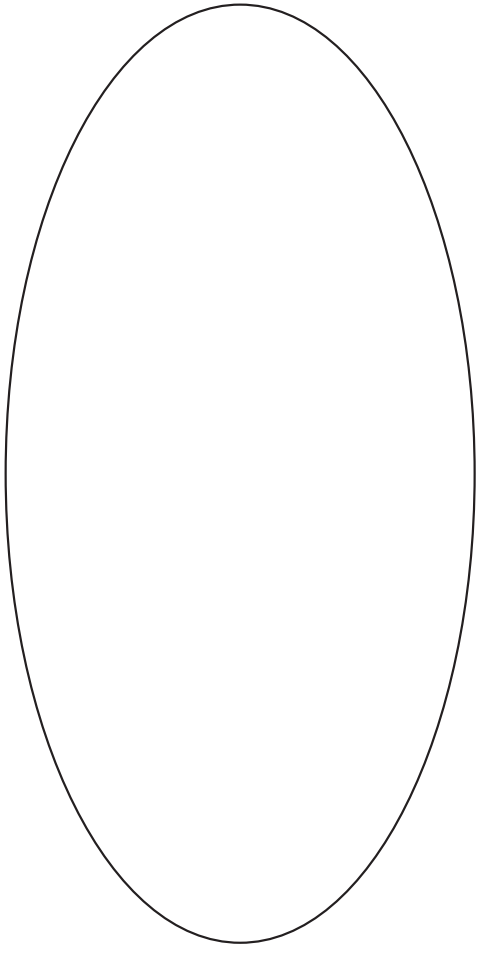

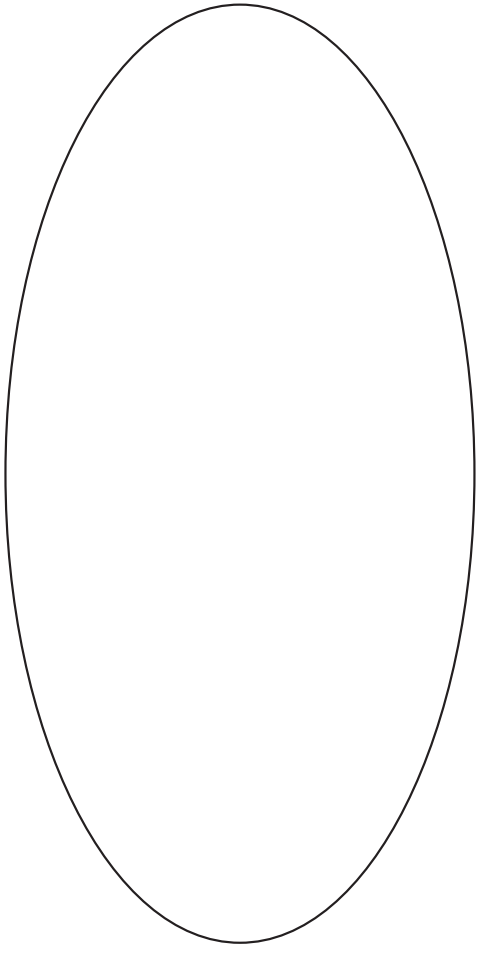

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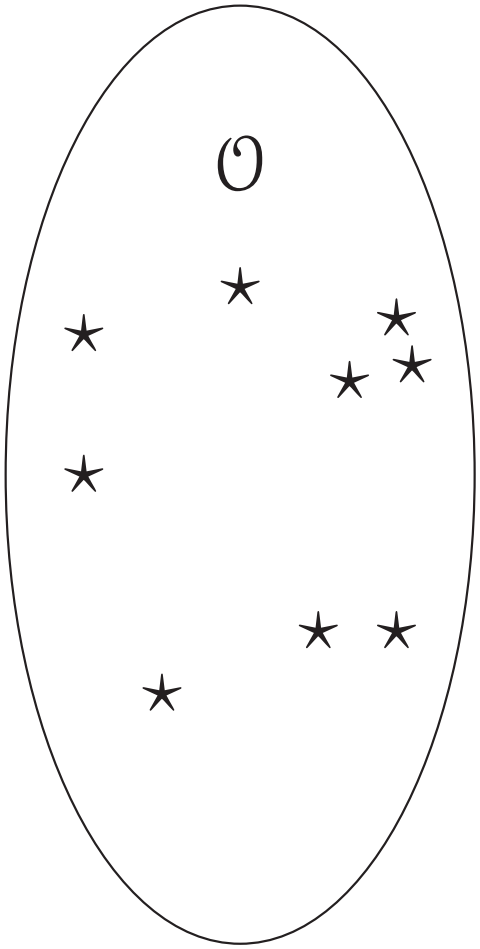

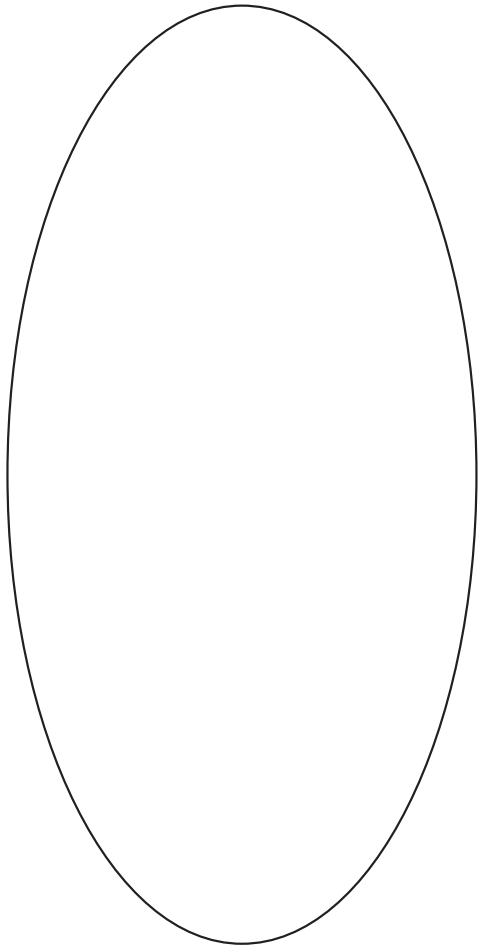

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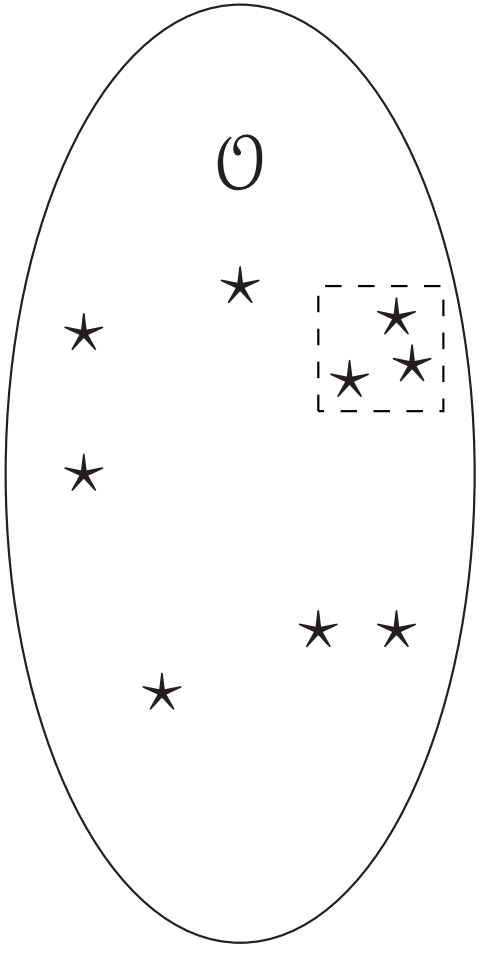

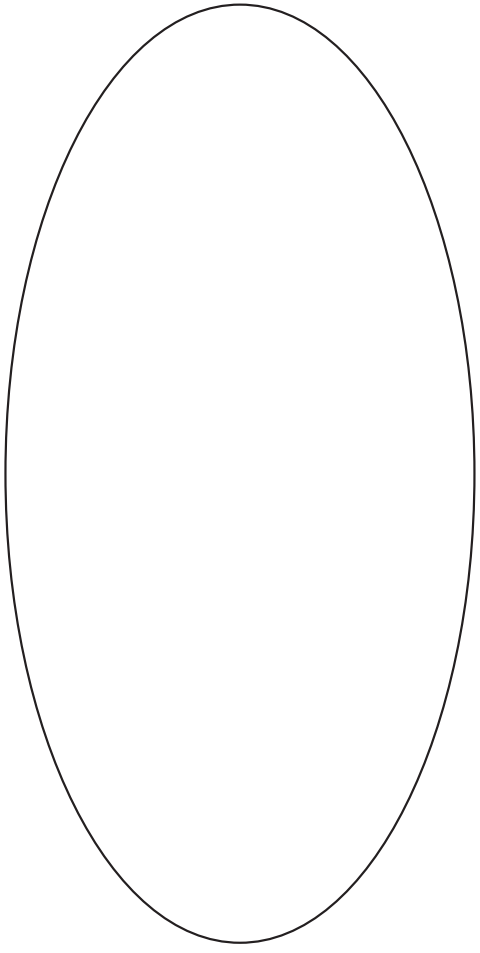

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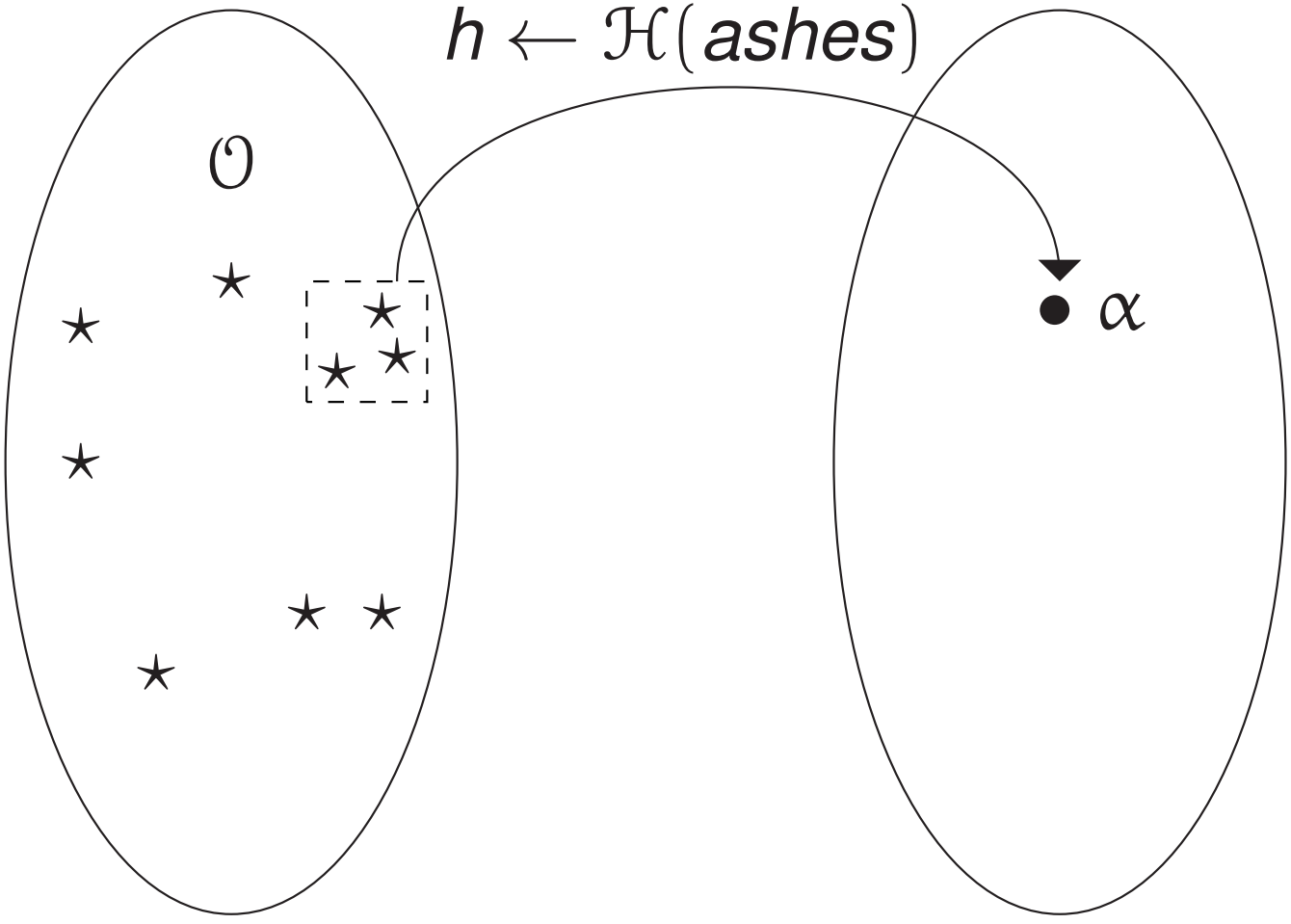
$h \leftarrow \mathcal{H}(ashes)$



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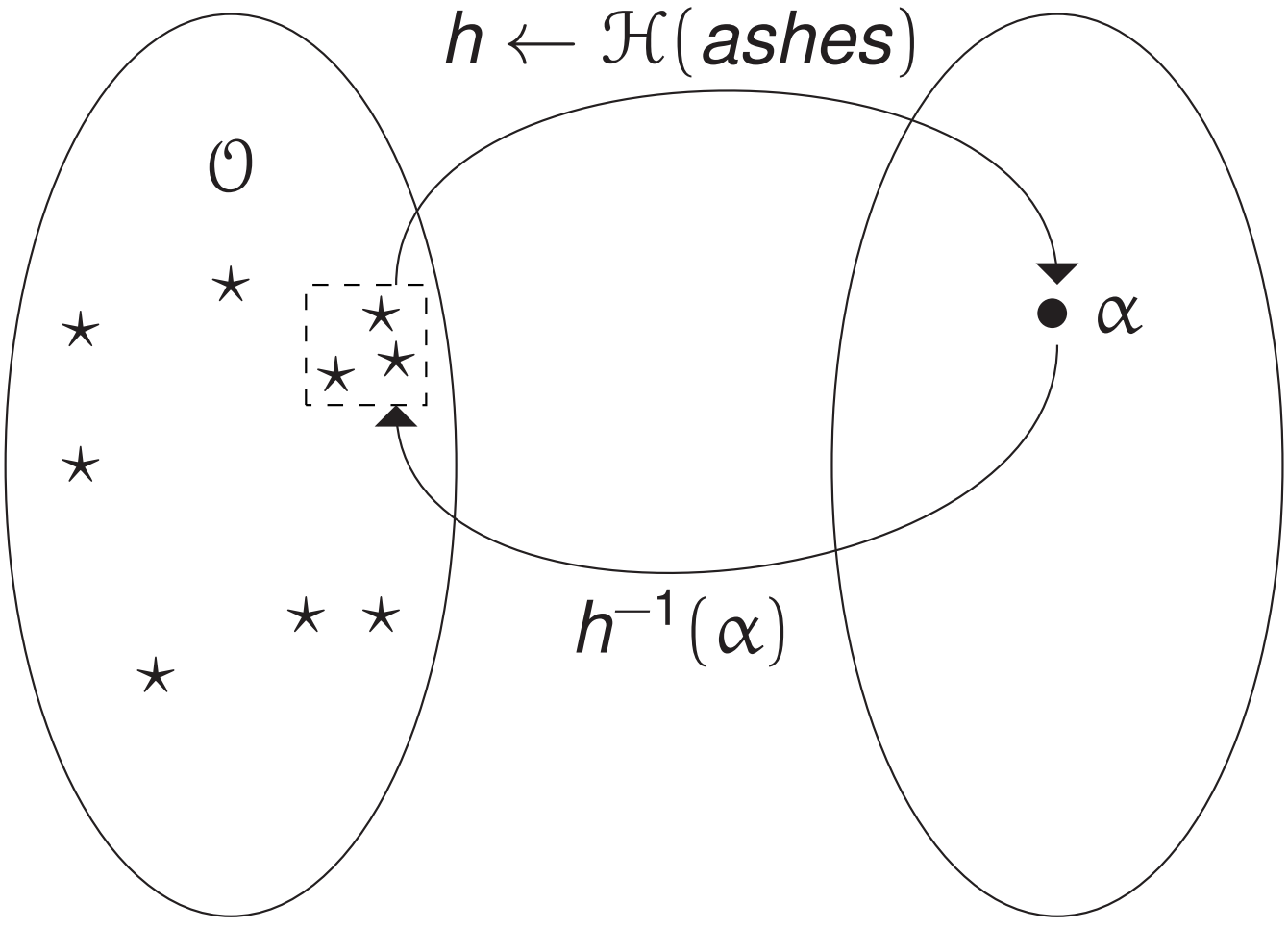

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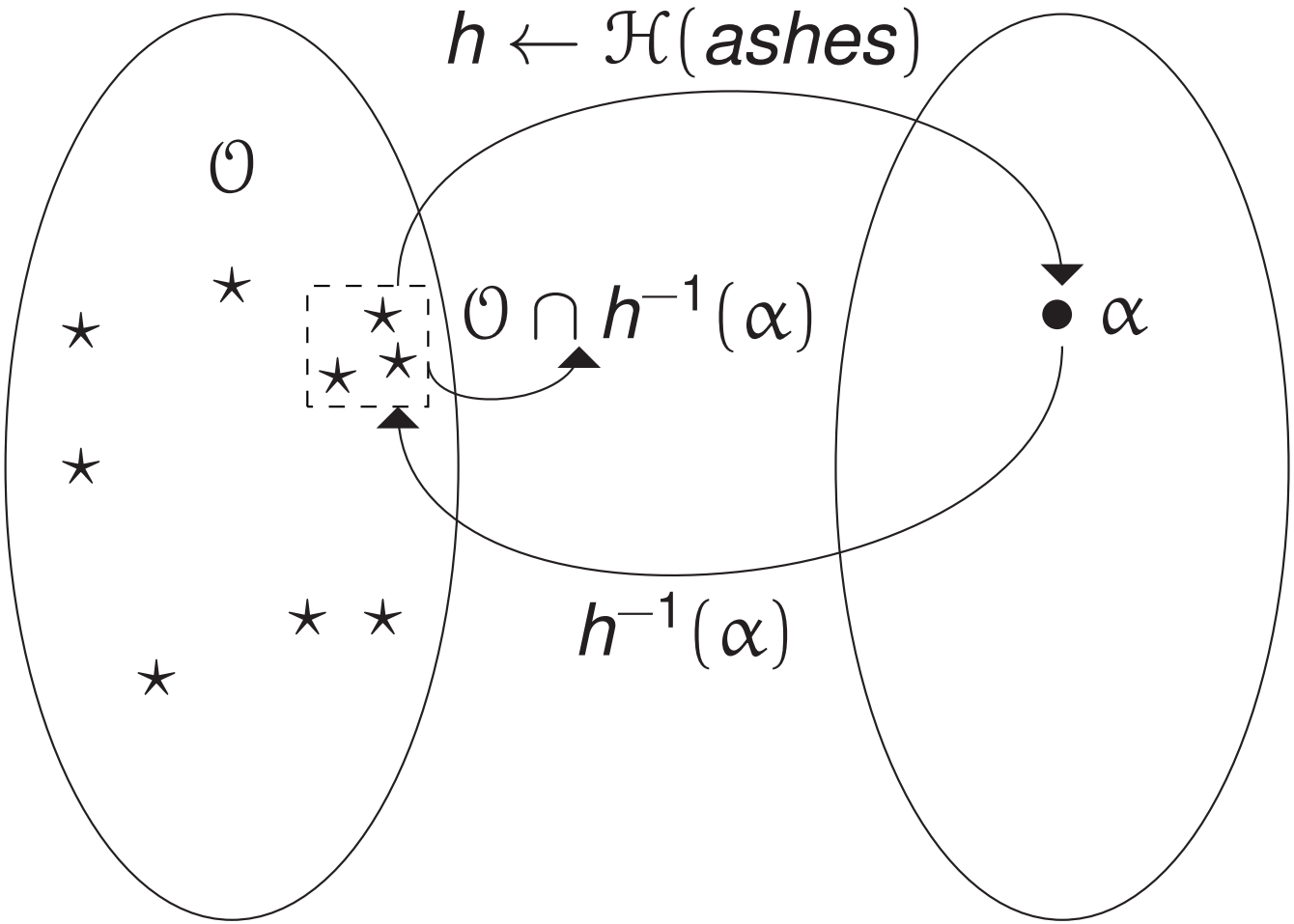

Did we reach uniformity?

No! But, we are closer. We proved **near-uniformity**.

There is a factor on the cell selection process that produces **intersection of cells**

The **Central Limit Theorem** affects within these intersections

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Experimentation

We used **CodeFlaws** for our experiments

We compared with a **human test suite**, **CBMC** and **CAVM**

Our measure focused on **coverage**, **mutations** and **faults detected**

Coverage

Testing Method	Lines	Branch
Original TS (main)	100% ± 6.9	100% ± 11.6
OD (main)	69.2% ± 19.5	50.0% ± 25.0
OD (main + final state)	100% ± 11.2	100% ± 16.7
CBMC (Lines)	100% ± 12.0	96.9% ± 22.5
CBMC (Branch)	100% ± 12.1	100% ± 23.3
CBMC (Condition)	100% ± 13.9	100% ± 18.3
CBMC (Decision)	100% ± 13.5	100% ± 21.3
CBMC (MCDC)	100% ± 14.4	100% ± 19.1
CAVM	100% ± 0.0	100% ± 12.0

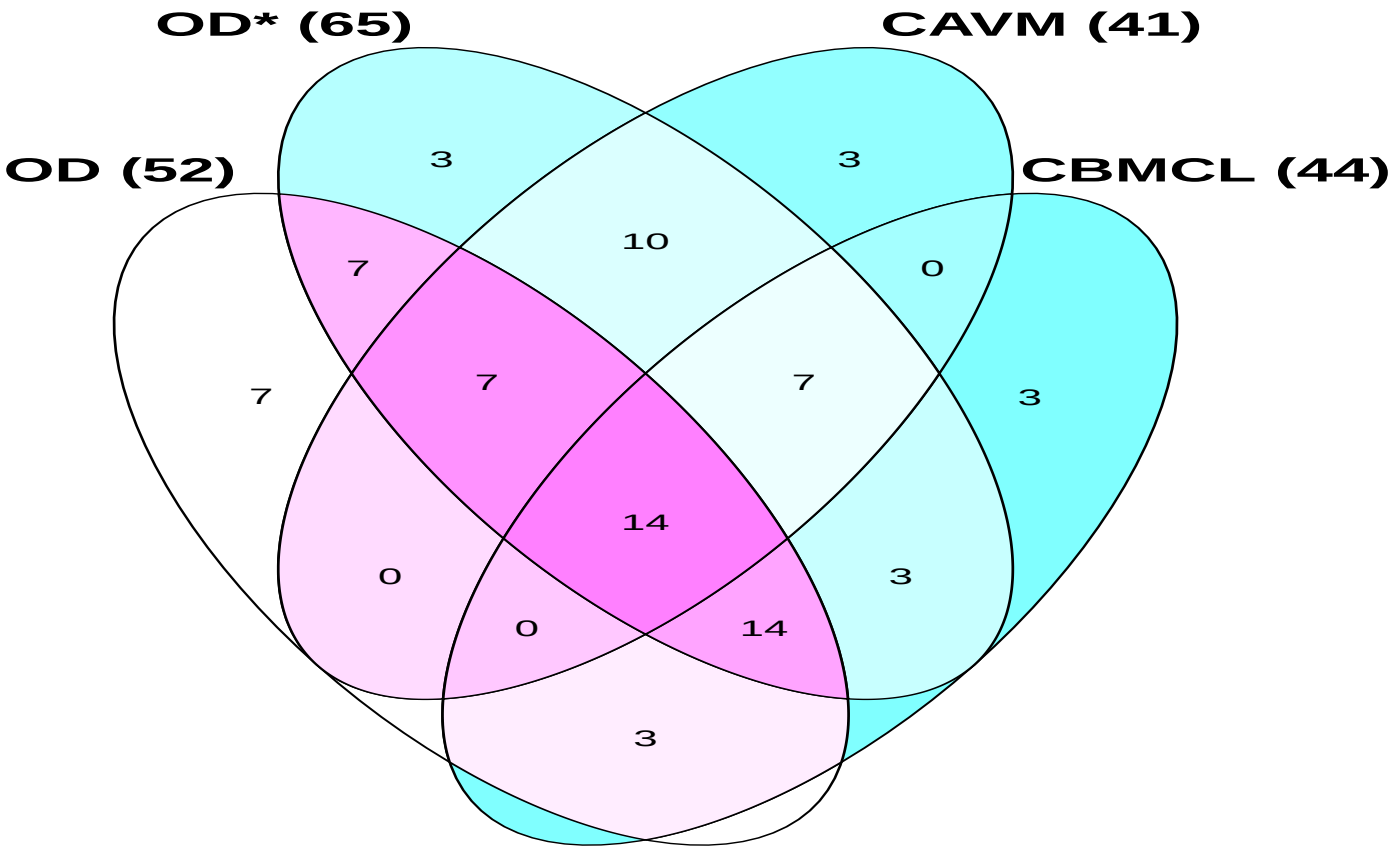
Killing mutants

Testing Method	Killed	Not Killed
Original TS	90.80%	9.20%
OD	71.43%	28.57%
OD (+ final state)	87.50%	12.50%
CBMC (Line)	78.57%	21.43%
CBMC (Branch)	78.57%	21.43%
CBMC (Condition)	85.71%	14.29%
CBMC (Decision)	81.48%	18.52%
CBMC (MCDC)	85.71%	14.29%
CAVM	77.78%	22.22%

Fault detection

Testing Method	Found	Not Found
Original TS	98%	2%
OD	52%	48%
OD (+ final state)	65%	35%
CBMC (Line)	44%	56%
CBMC (Branch)	31%	69%
CBMC (Condition)	37%	63%
CBMC (Decision)	31%	69%
CBMC (MCDC)	34%	66%
CAVM	41%	59%

Fault detection



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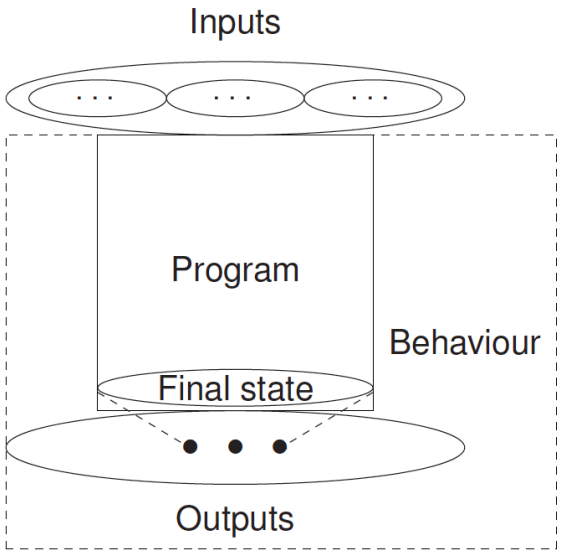

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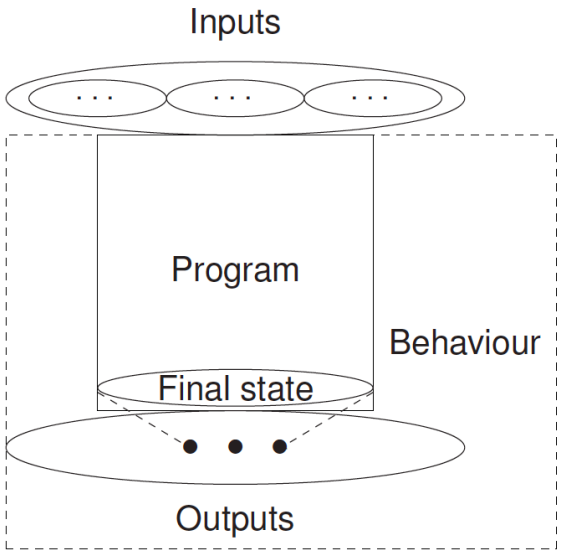

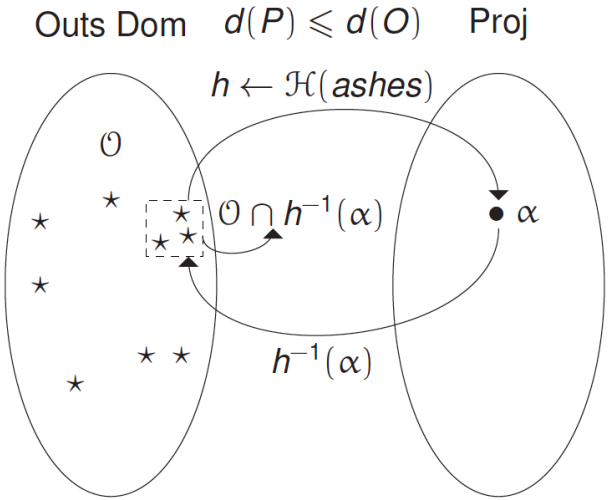

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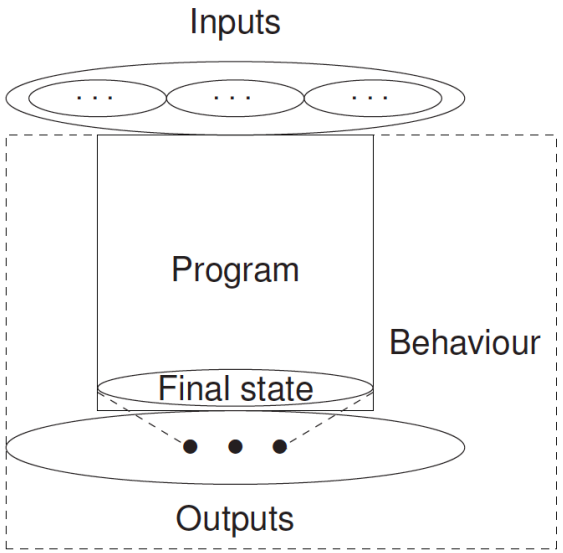

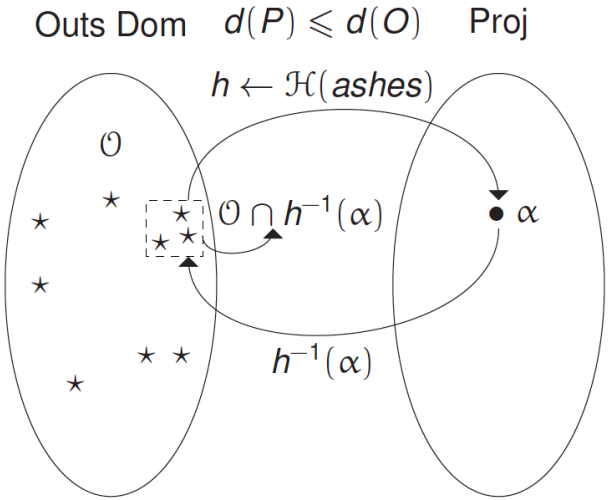

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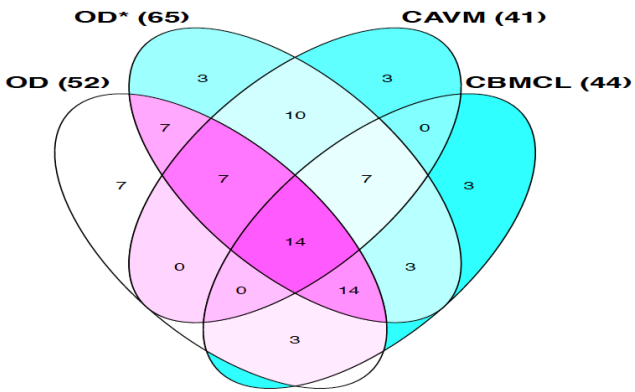

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