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LeanBin: Harnessing Lifting and Recompilation to Debloat Binaries

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LeanBin

Binary Lifting

Reverse Engineering
Program Analysis
Patching
Recompilation

Binary Debloating

Security
Attack Surface Reduction
Specialisation

Hybrid Approach

↓

Static Analysis + Dynamic Analysis

↓

Fast + Precise

MOTIVATION

(With related work)

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Software is Imperfect

- Binaries and libraries can be exploited
- Bigger the binary, bigger the attack surface
- Often the whole binary is not needed (legacy code, unused functionality, etc.)

Software Debloating

- Remove unused code or keep what is needed
- Software debloating / specialisation can create new binaries with a smaller attack surface

Software Debloating

- Source code is not always available
- But debloating binaries directly lacks portability
- Binaries can be lifted to higher-level IR first, then be debloated and recompiled

Software Debloating

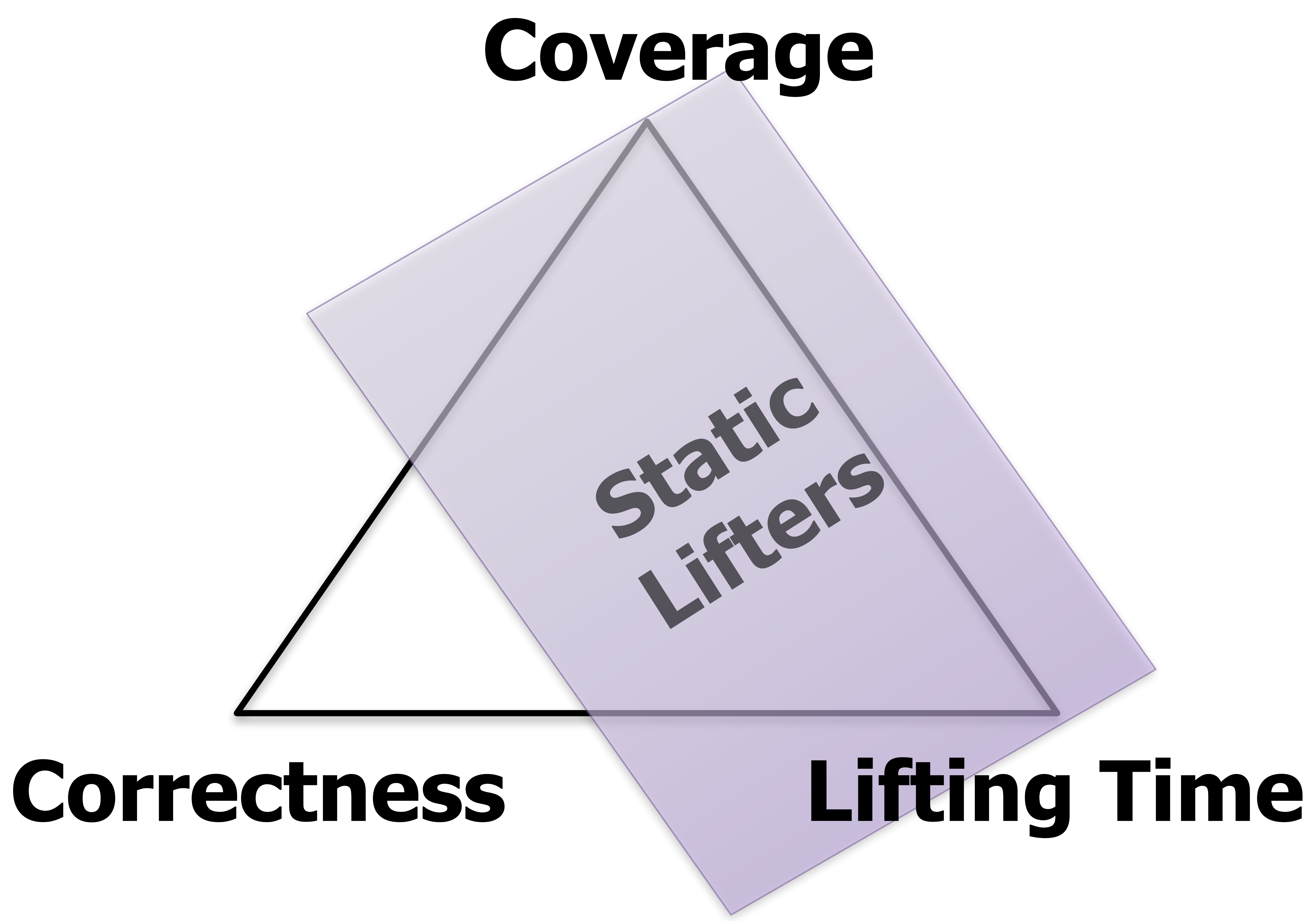
- **Only BinRec combines flexibility of binary debloating and reuse of the compiler infrastructure by the means on binary lifting and recompilation**
- **… But BinRec has limitations in the way it does lifting**

Into Lifting

So let’s talk about binary lifters…

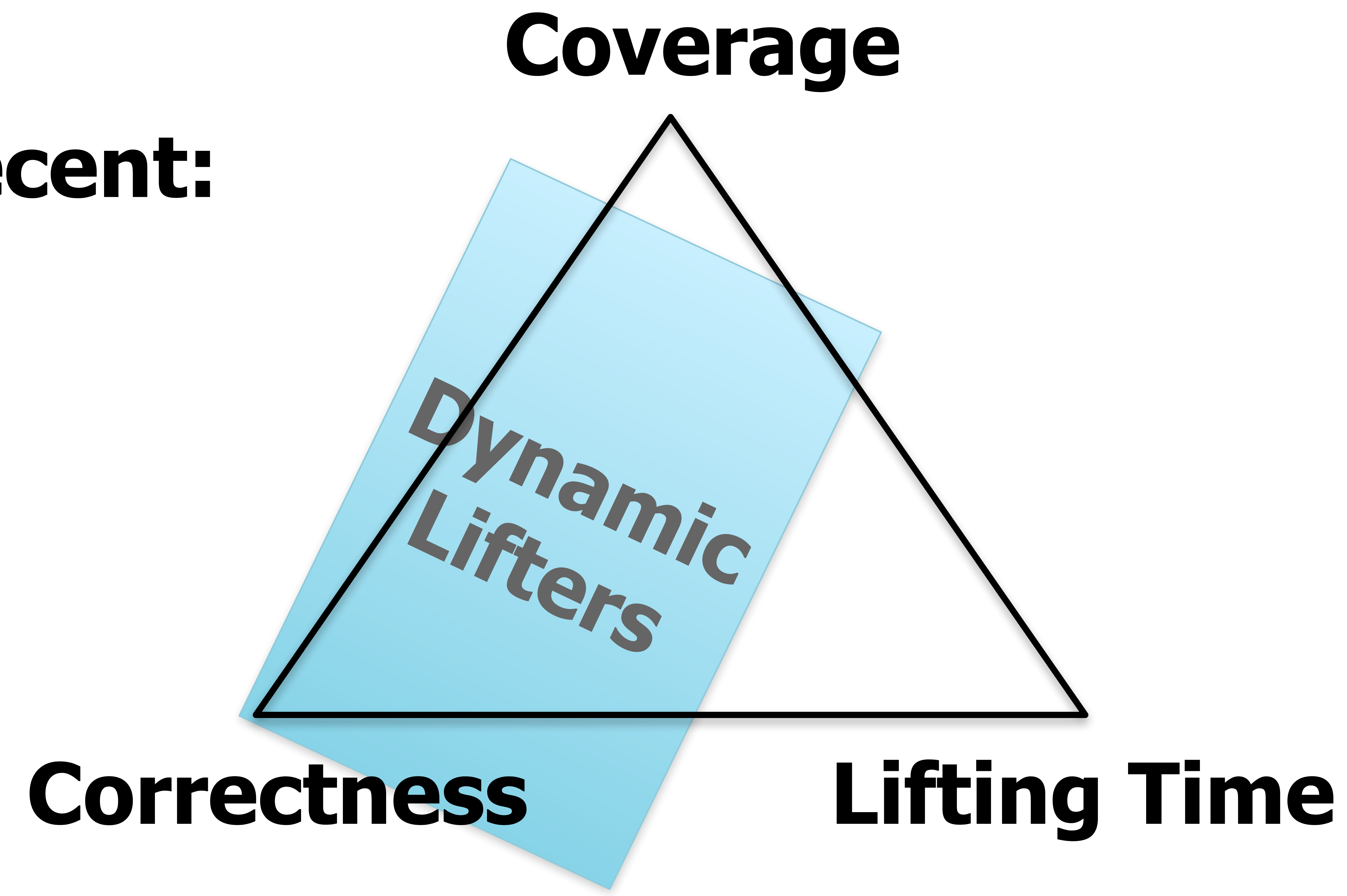
Binary Lifting

- **Static lifter are prevalent:**
  - **Fast**
  - **High coverage**
  - **Use heuristics**



Binary Lifting

- Dynamic lifters are more recent:
  - Slower
  - Heuristic free
  - Limited coverage



Question

Can we combine benefits of both to support binary debloating?

OUR APPROACH

Our Approach

- Indirect control-flow cannot always be statically analysed…
  - So use dynamic analysis to discover indirect control flow
- But direct branches can…
  - So use heuristc-free static analysis to expand the control-flow beyond dynamic analysis

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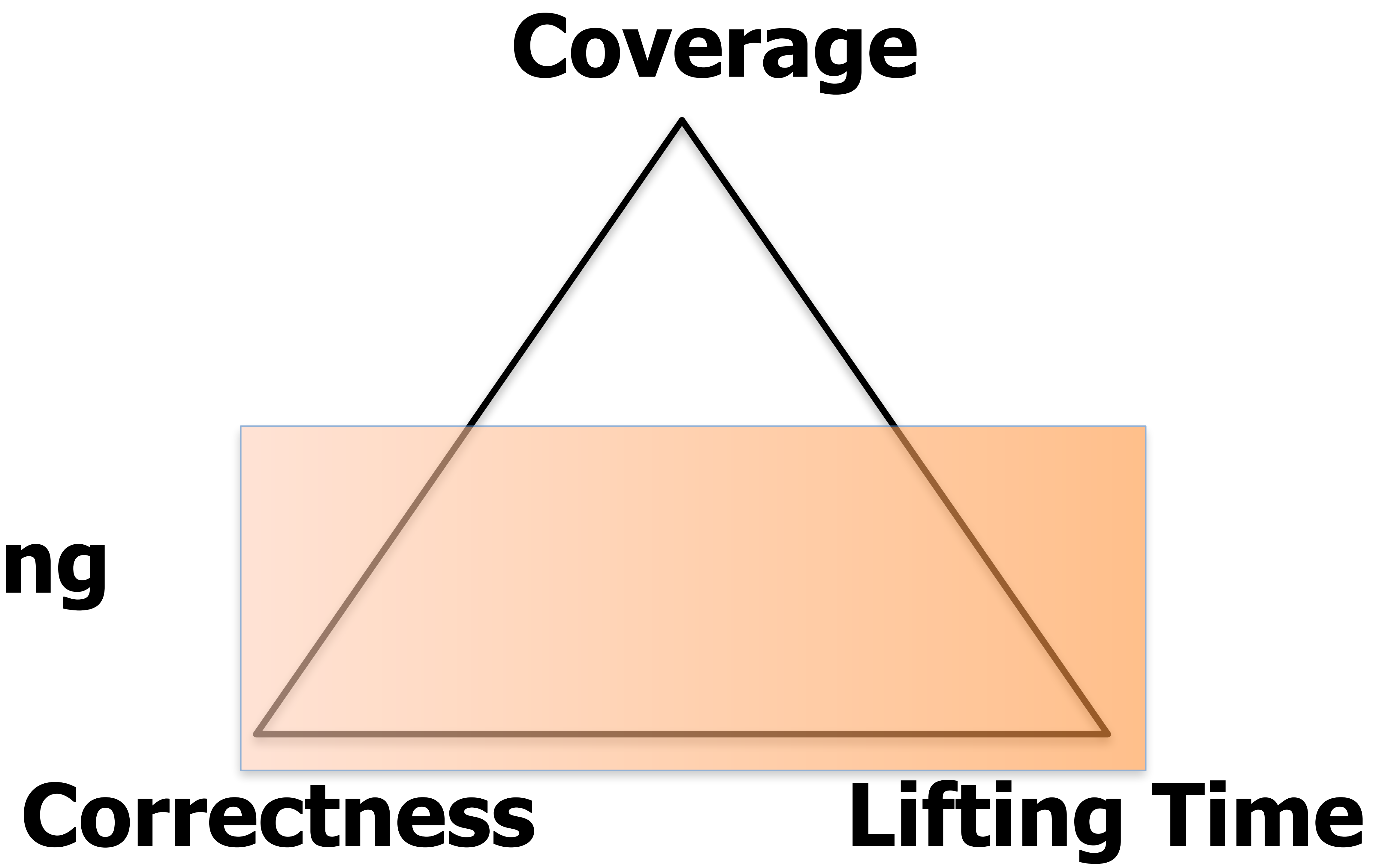
Hybrid Lifting

- **Novel hybrid lifting:**
  - **Fast**
  - **Can have limited coverage**
    - **But that is okay for debloating**
  - **Heuristic free**



System Overview

DYNAMIC
STATIC
01
BINARY
CONCRETE EXECUTION TRACER
A
CONCRETE INPUTS
?
STATIC ANALYSIS
B
CFG STRUCTURING
C
CODE GENERATION
D
C CODE
CLANG
LLVM IR

DEBLOATING STRATEGIES

(With an example)

Debloating Strategies

```
example:
  cmp x0, x1
  b.eq cond1
  add x2, x0, x1
  b end_cond

cond1:
  sub x2, x0, x1

end_cond:
  cmp x0, x1
  b.eq func1
  bl foo
  b end_func

func1:
  bl bar

end_func:
  ret
```

Not Executed = Undiscovered

Dynamic

`x0 = 1 and x1 = 1`

Debloating Strategies

```
example:
  cmp x0, x1
  b.eq cond1
  add x2, x0, x1
  b end_cond

cond1:
  sub x2, x0, x1

end_cond:
  cmp x0, x1
  b.eq func1
  bl foo
  b end_func

func1:
  bl bar

end_func:
  ret
```

Statically Analysed

Branches outside the function so not followed

Dynamic + Static 1

`x0 = 1 and x1 = 1`

Only follow internal control flow

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Debloating Strategies

```
example:
   cmp x0, x1
   b.eq cond1
   add x2, x0, x1
   b end_cond

cond1:
   sub x2, x0, x1

end_cond:
   cmp x0, x1
   b.eq func1
   bl foo
   b end_func

func1:
   bl bar

end_func:
   ret
```

All direct branches followed

Dynamic + Static 2

`x0 = 1 and x1 = 1`

Follow all control flow

Debloating Strategies

```
example:
   cmp x0, x1
   b.eq cond1
   add x2, x0, x1
   b end_cond

cond1:
   sub x2, x0, x1

end_cond:
   cmp x0, x1
   b.eq func1
   blr x0 ✗
   b end_func

func1:
   blr x1

end_func:
   ret
```

Direct branches can be followed

`x0 = 1 and x1 = 1`

Indirect branch instead

Not executed indirect branches cannot be followed

Executed indirect branches can be followed

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IMPLEMENTATION

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Implementation

- Targets 64-bit ARM (AArch64) binaries and libraries
- Supports optimised binaries with non-trivial control flow (indirect branches, callbacks)

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RESULTS

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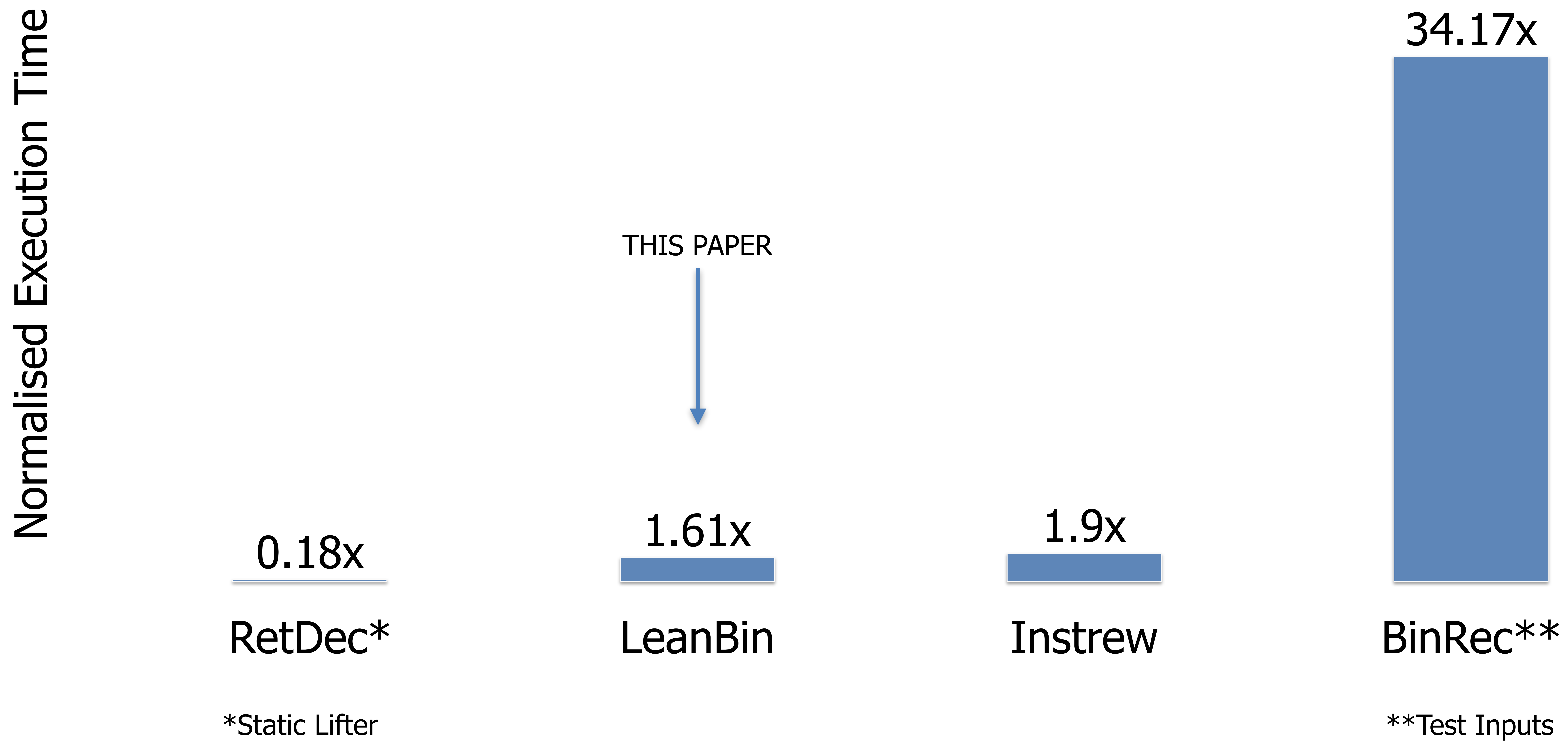
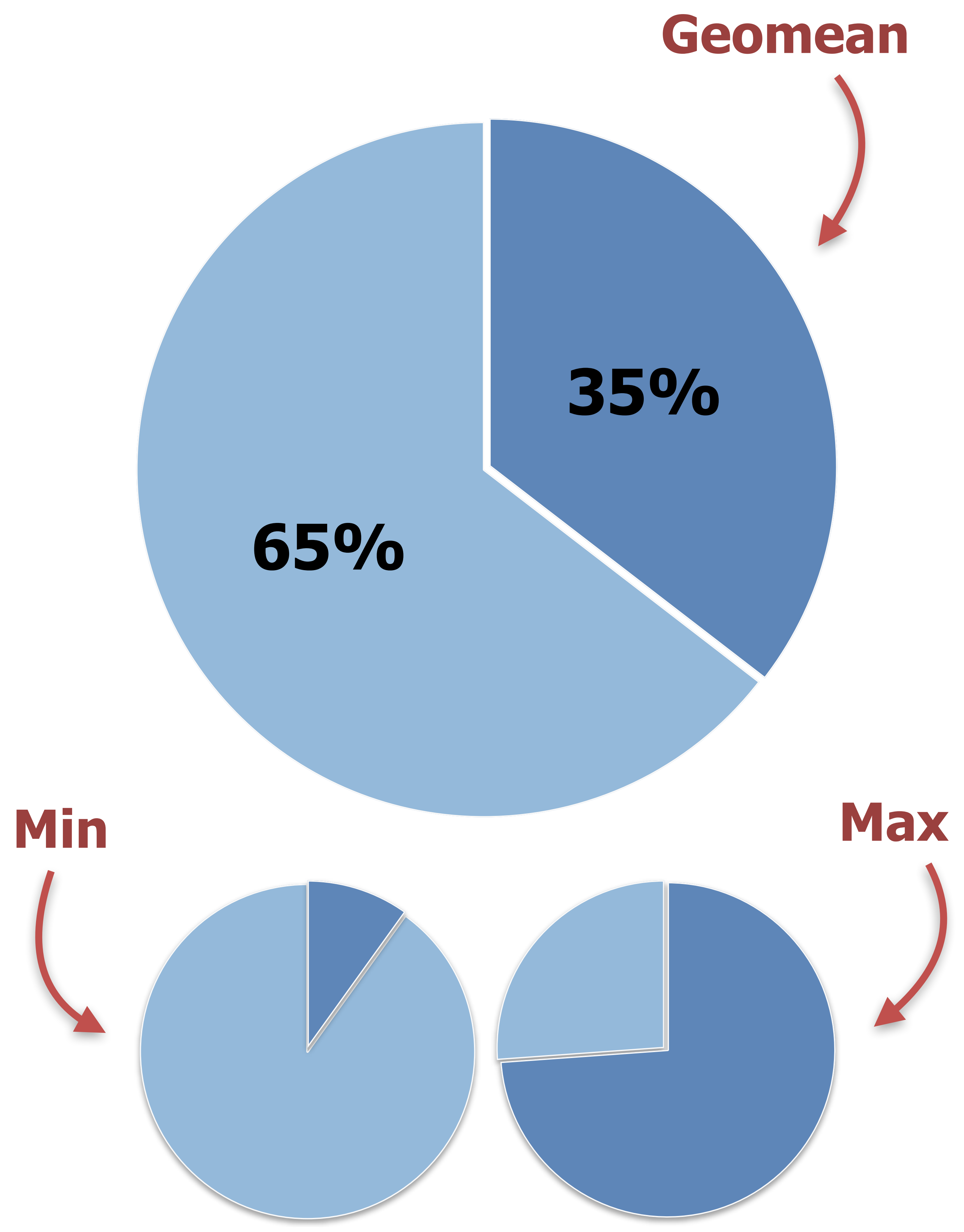
Performance Overhead of Lifting



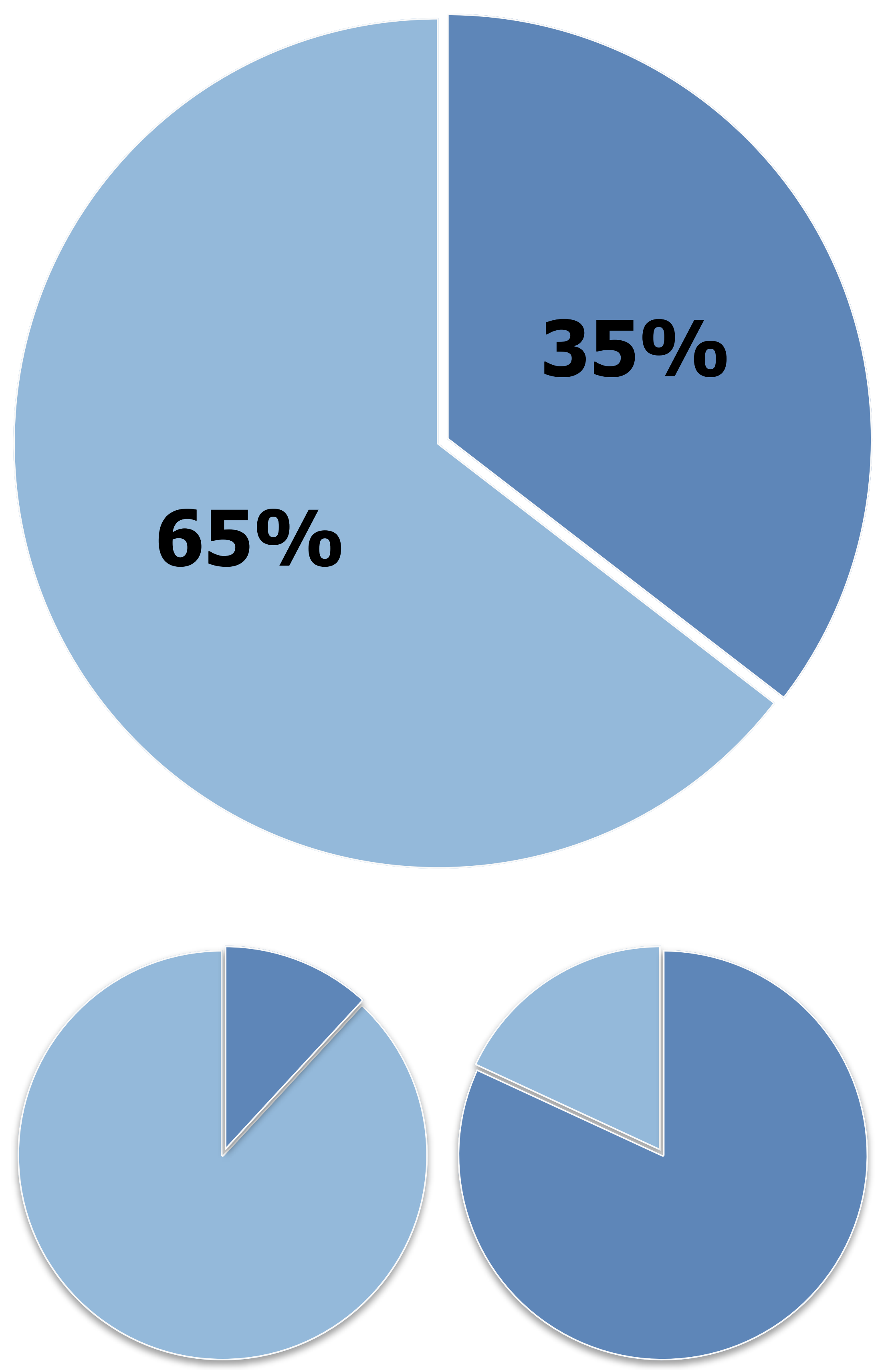
Coverage

SPEC CPU2006 INT

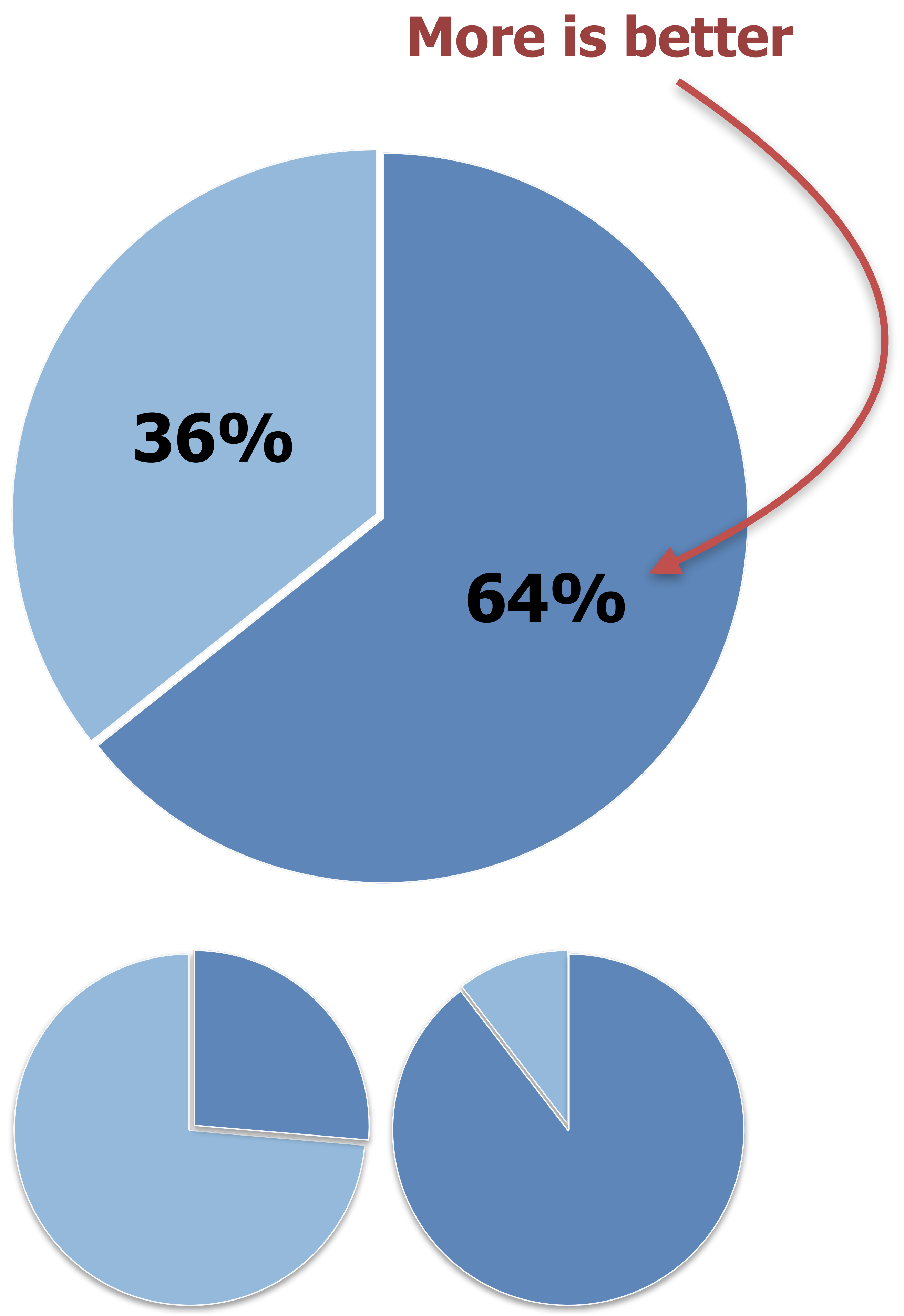
● Discovered ● Undiscovered



Dynamic



Dynamic + Static 1



Dynamic + Static 2

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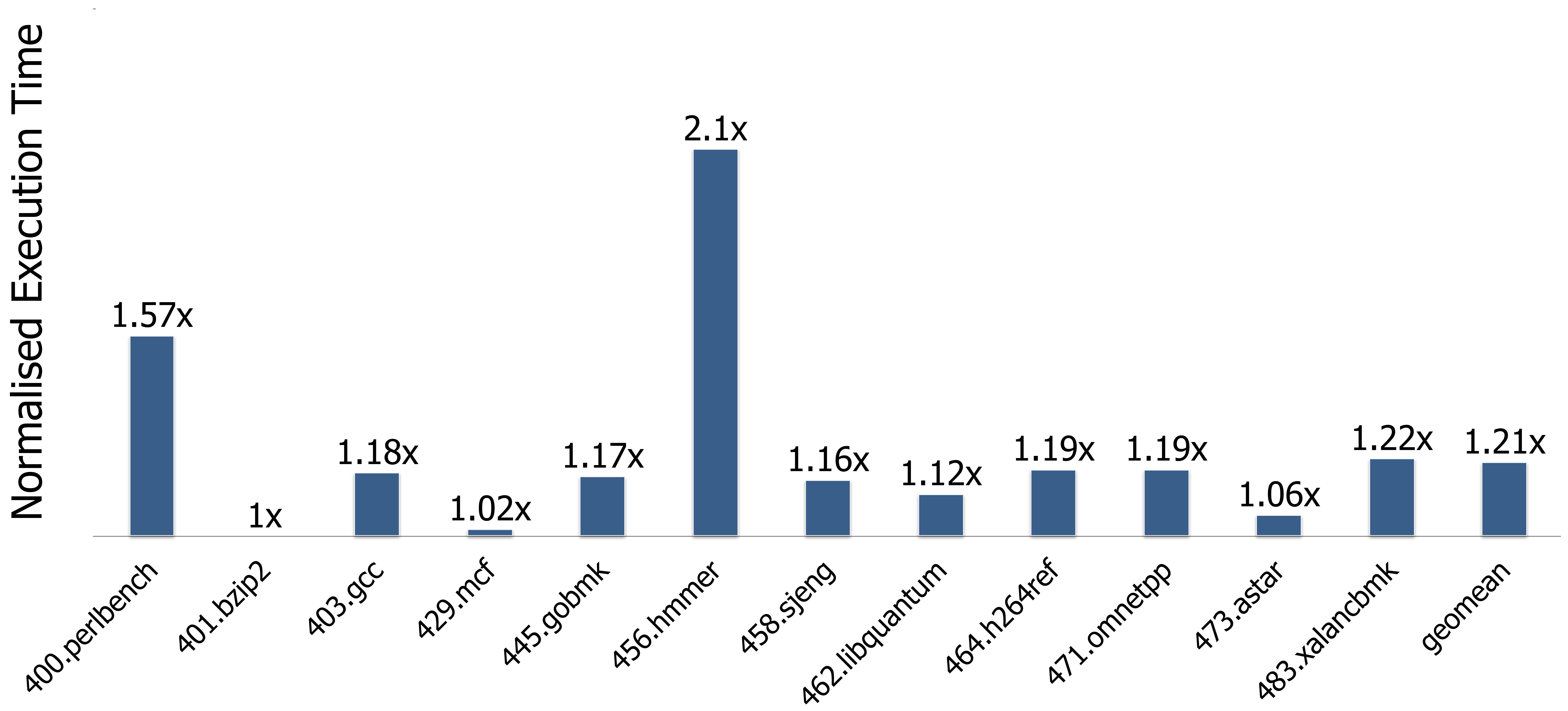
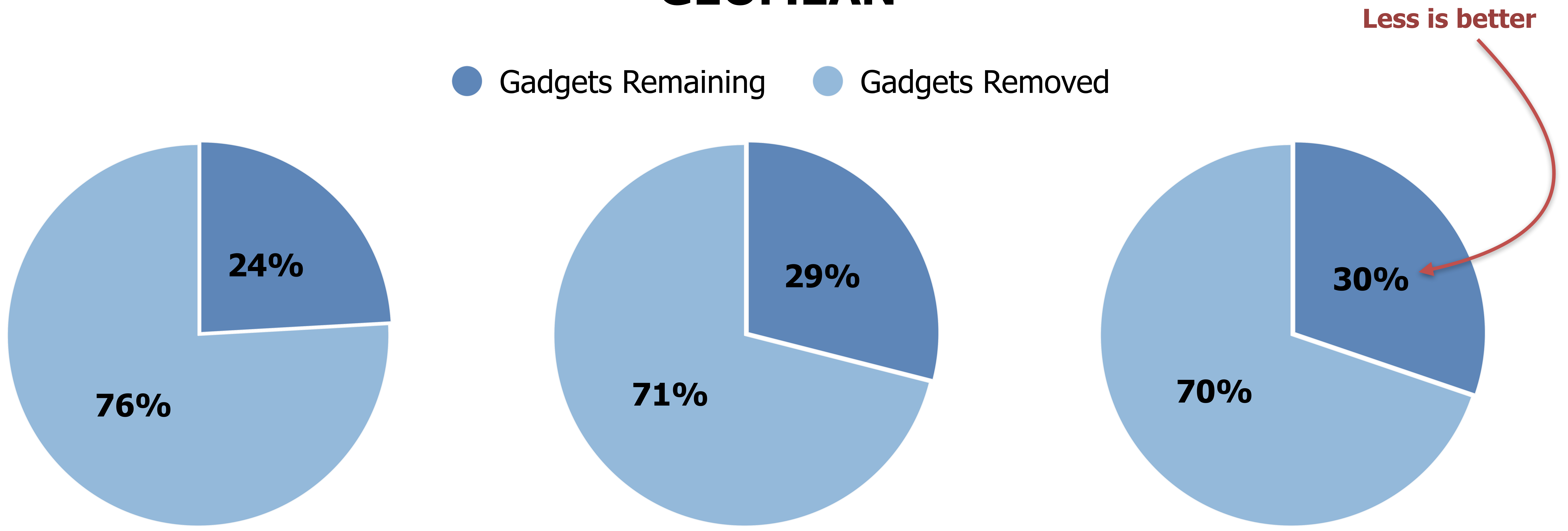
Debloated Binary Performance

SPEC CPU2006 INT



Gadgets

SPEC CPU2006 INT GEOMEAN



Dynamic **Dynamic + Static 1** **Dynamic + Static 2**

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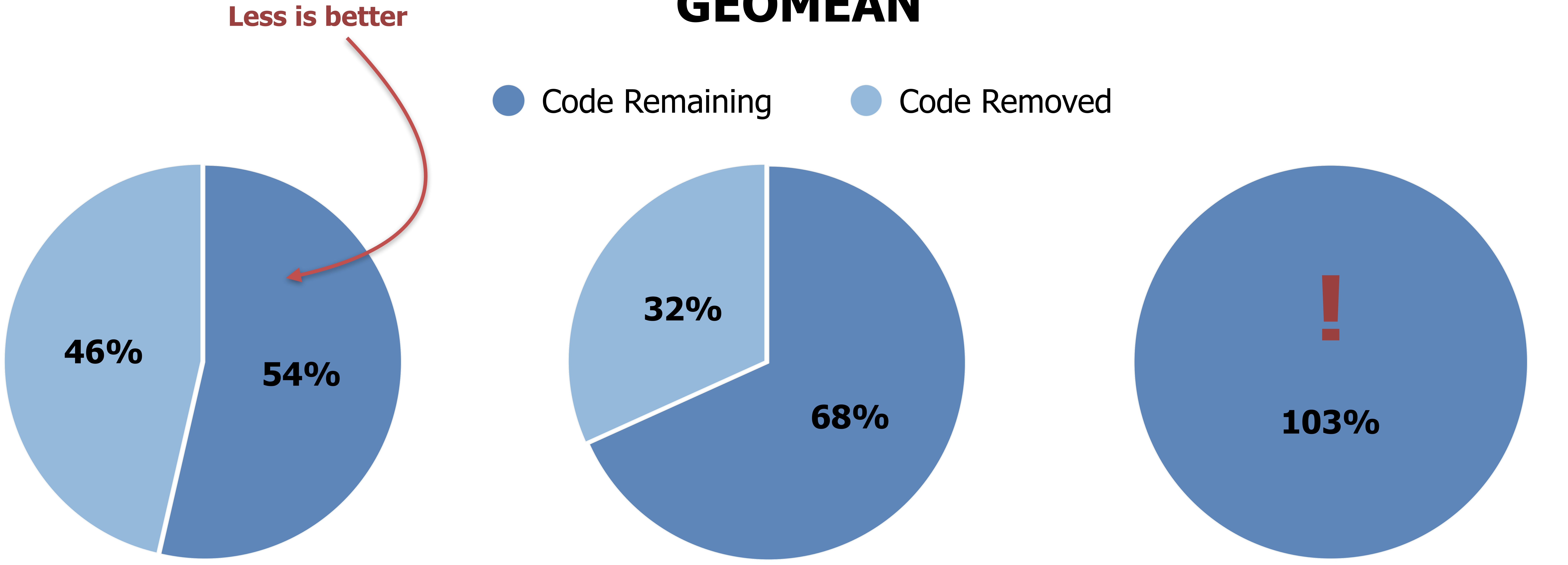
Code Size

SPEC CPU2006 INT GEOMEAN



Dynamic

Dynamic + Static 1

Dynamic + Static 2

CONCLUSIONS

Conclusions

- First binary debloater based on novel hybrid lifting combining dynamic and heuristic-free static analysis
- Open-source implementation for ARM 64-bit (AArch64) binaries

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Thanks!

UK Research and Innovation

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THE ROYAL SOCIETY

EPSRC
Engineering and Physical Sciences Research Council

MoatE (10017512) and Soteria (75243)

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CODE OPEN SOURCE ON GITHUB

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