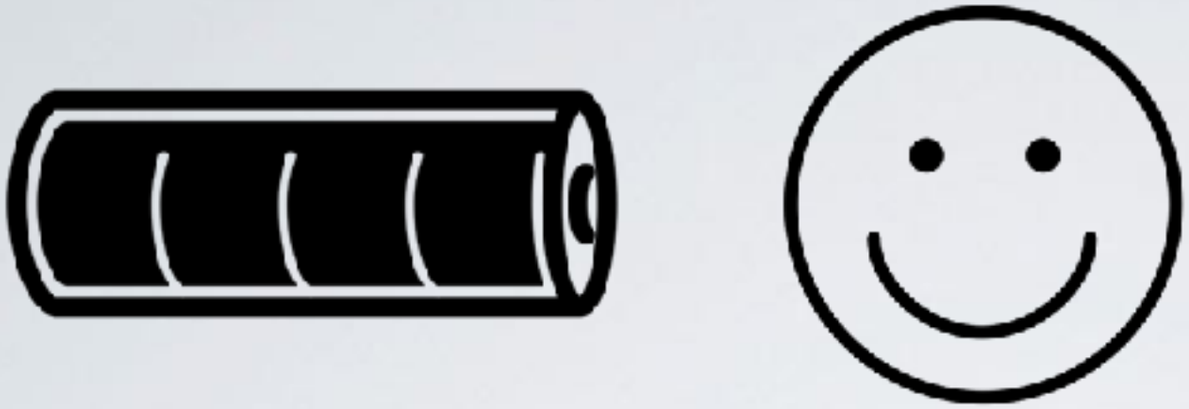
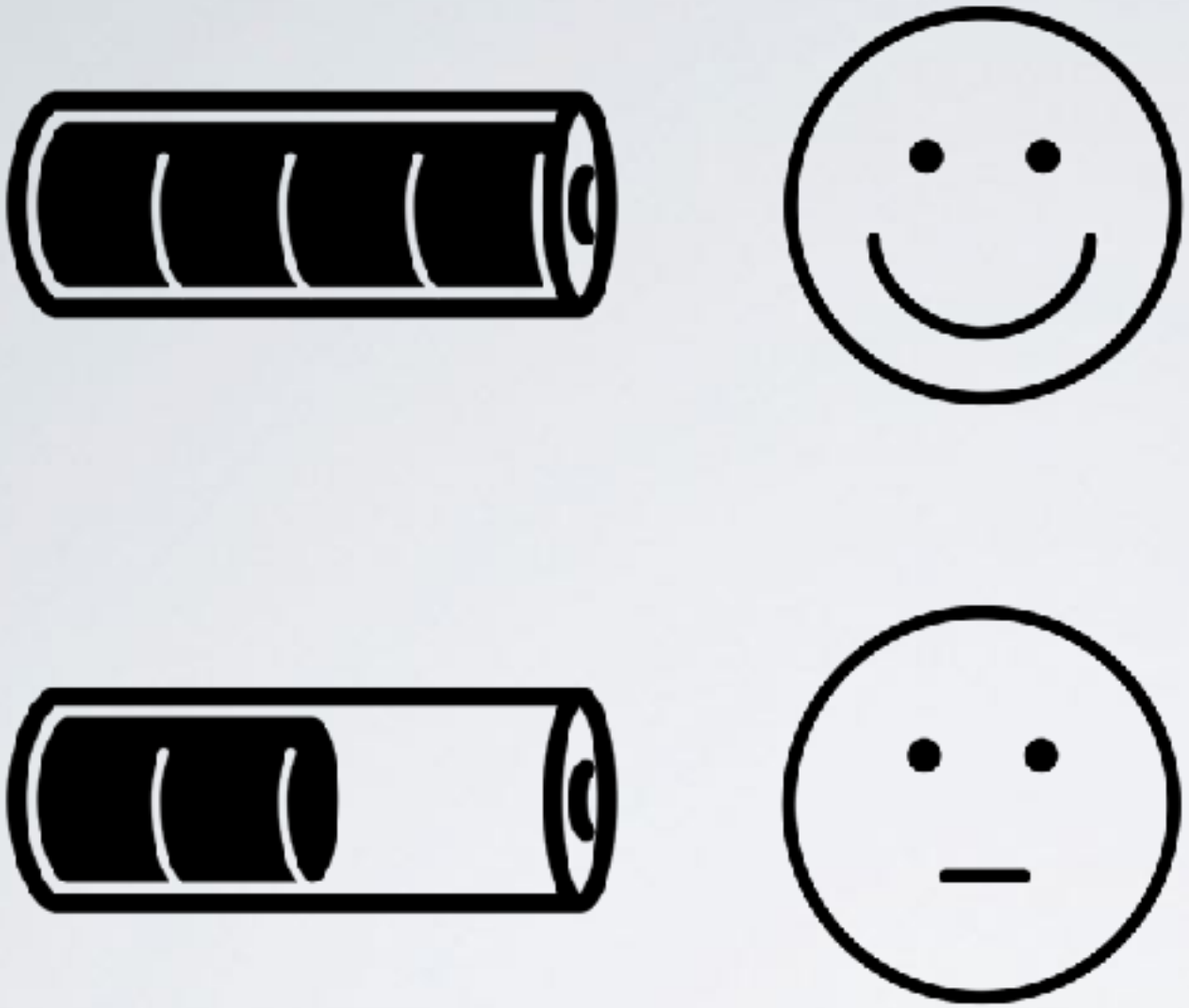
The road to:

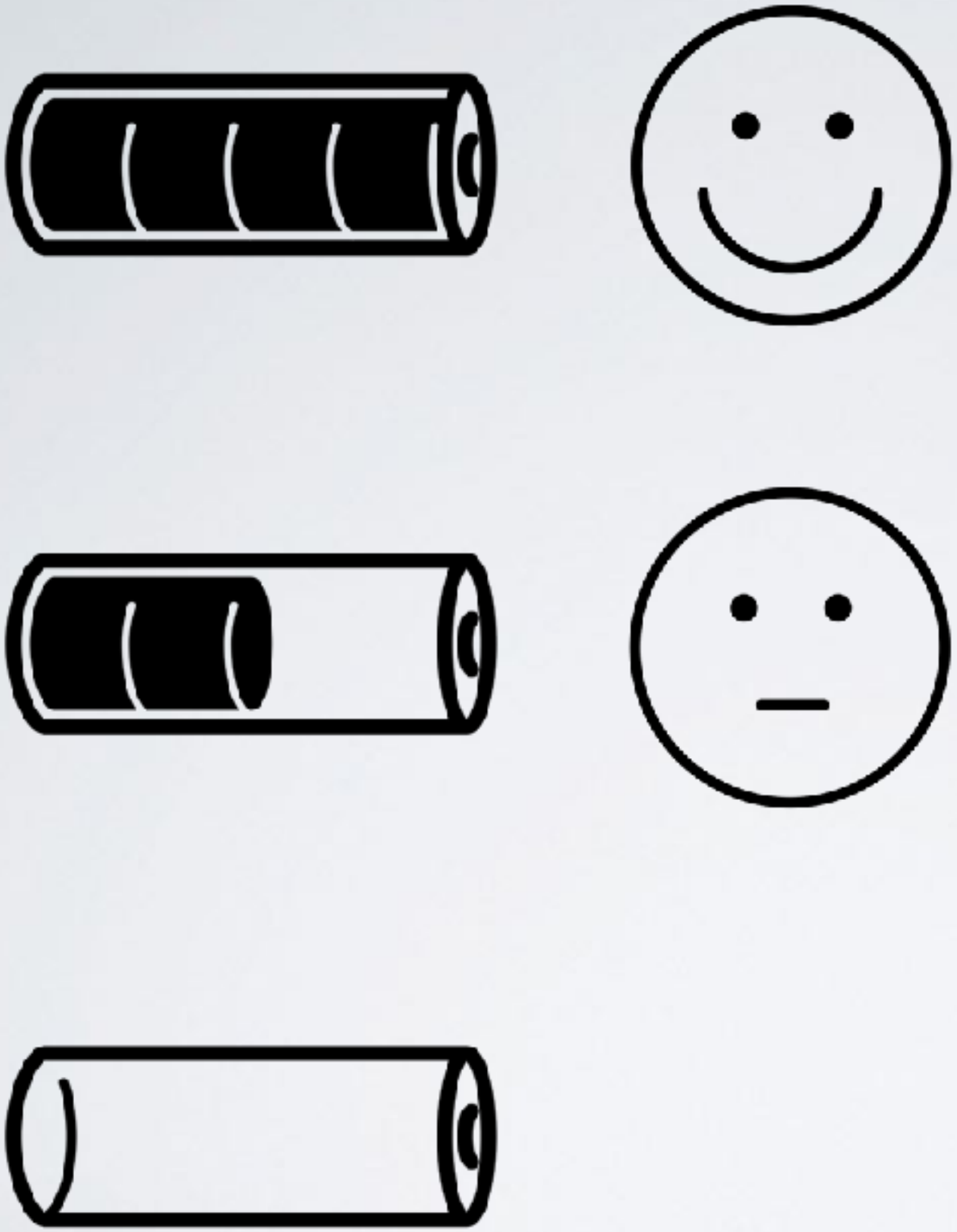
SEEDS: THE SOFTWARE ENGINEER'S ENERGY-OPTIMIZATION DECISION SUPPORT FRAMEWORK

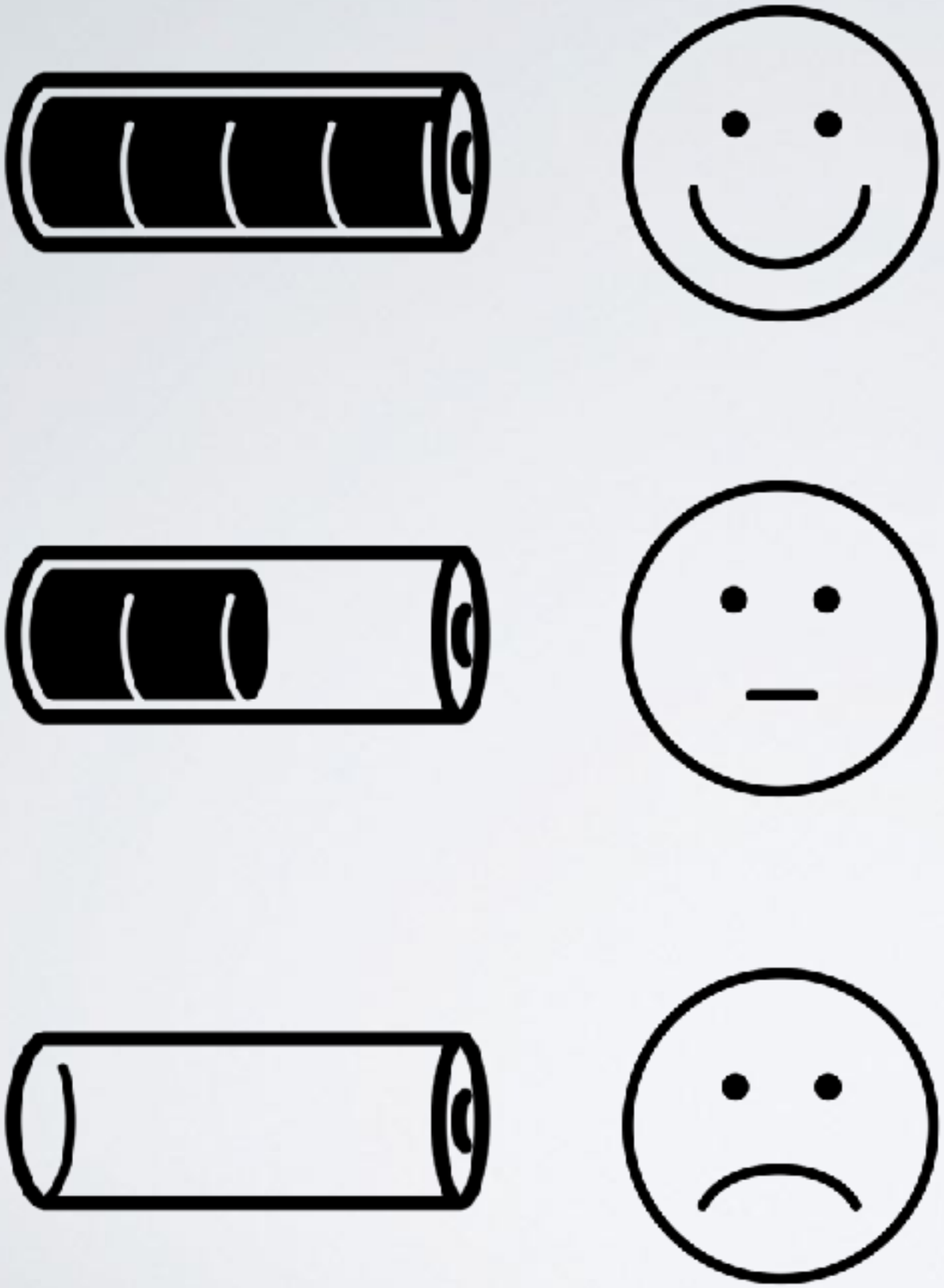
James Clause

University of Delaware



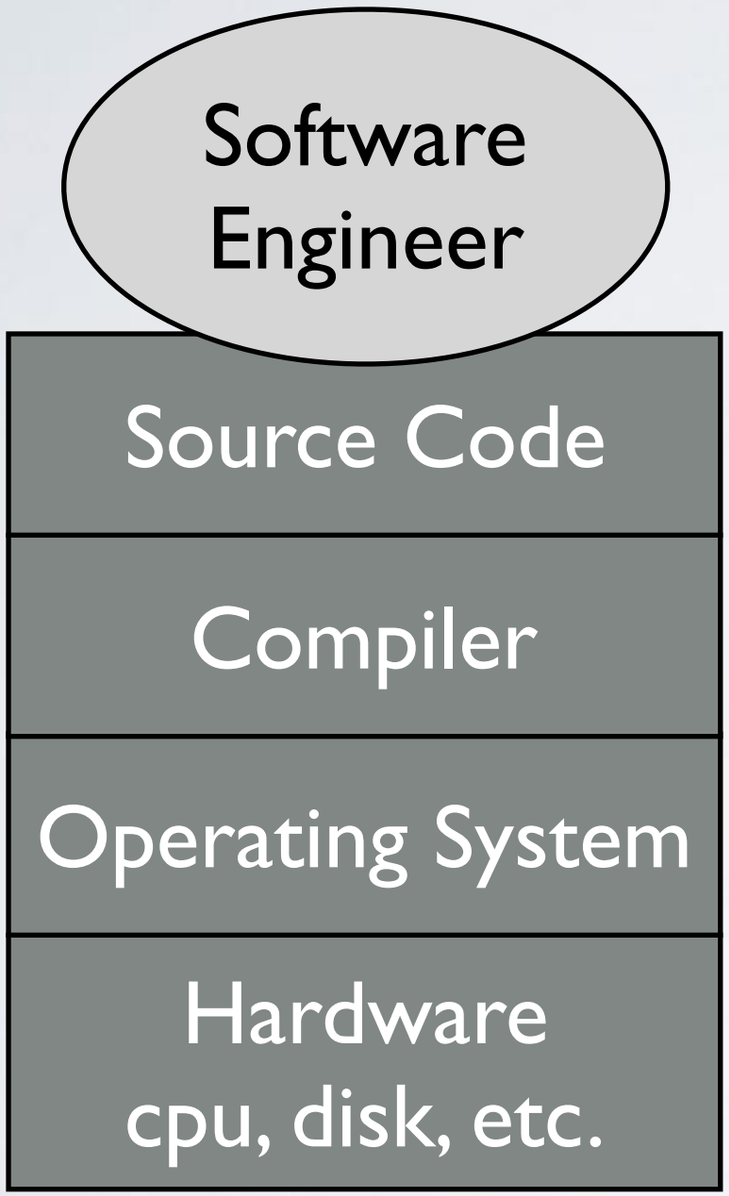




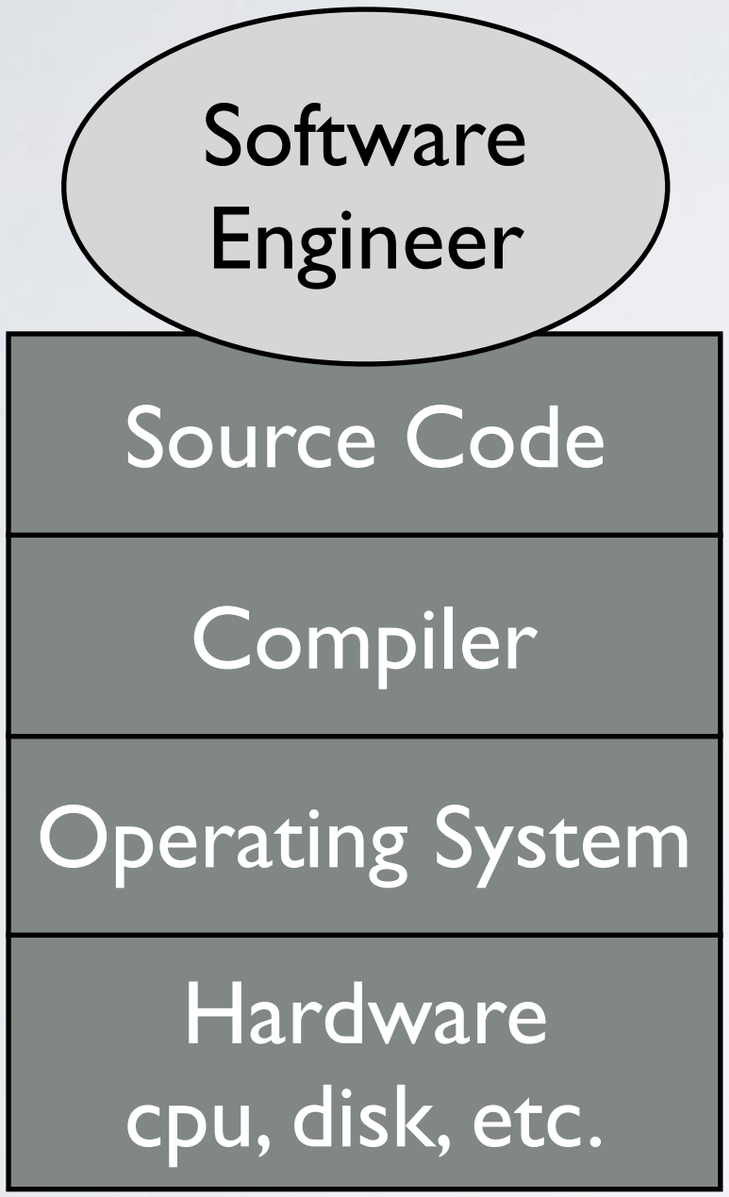


Energy usage is an increasingly important concern

REDUCING ENERGY USAGE



REDUCING ENERGY USAGE

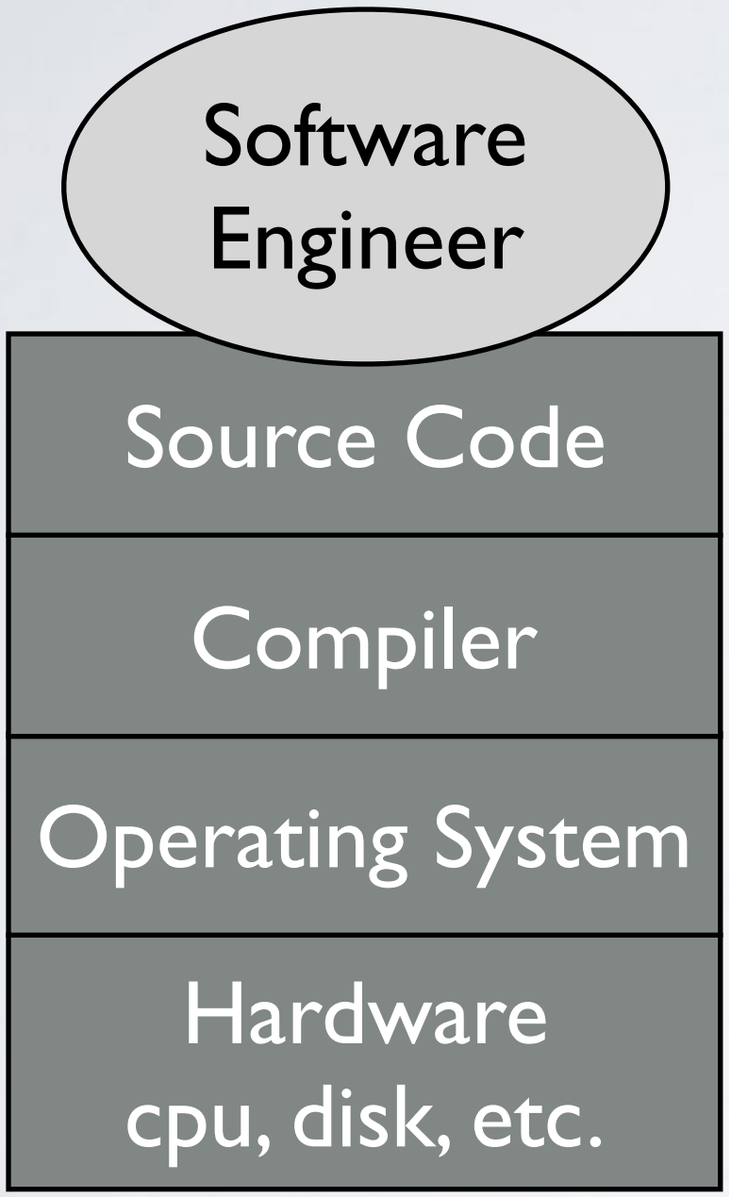


Energy Reducing Transformations

Batch operations

Dynamic Voltage Frequency Scaling

REDUCING ENERGY USAGE



Get software engineers involved!

Energy Reducing Transformations

Batch operations

Dynamic Voltage Frequency Scaling

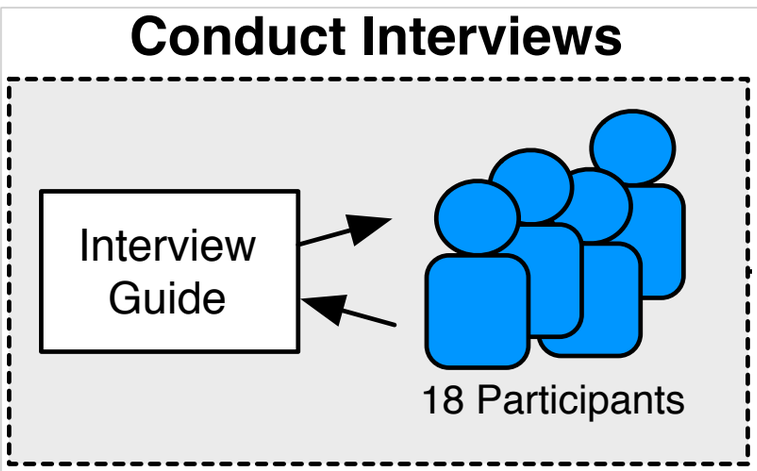
HOW DO SOFTWARE ENGINEERINGS THINK ABOUT ENERGY DURING DEVELOPMENT?

An Empirical Study of Practitioners' Perspectives on Green Software Engineering

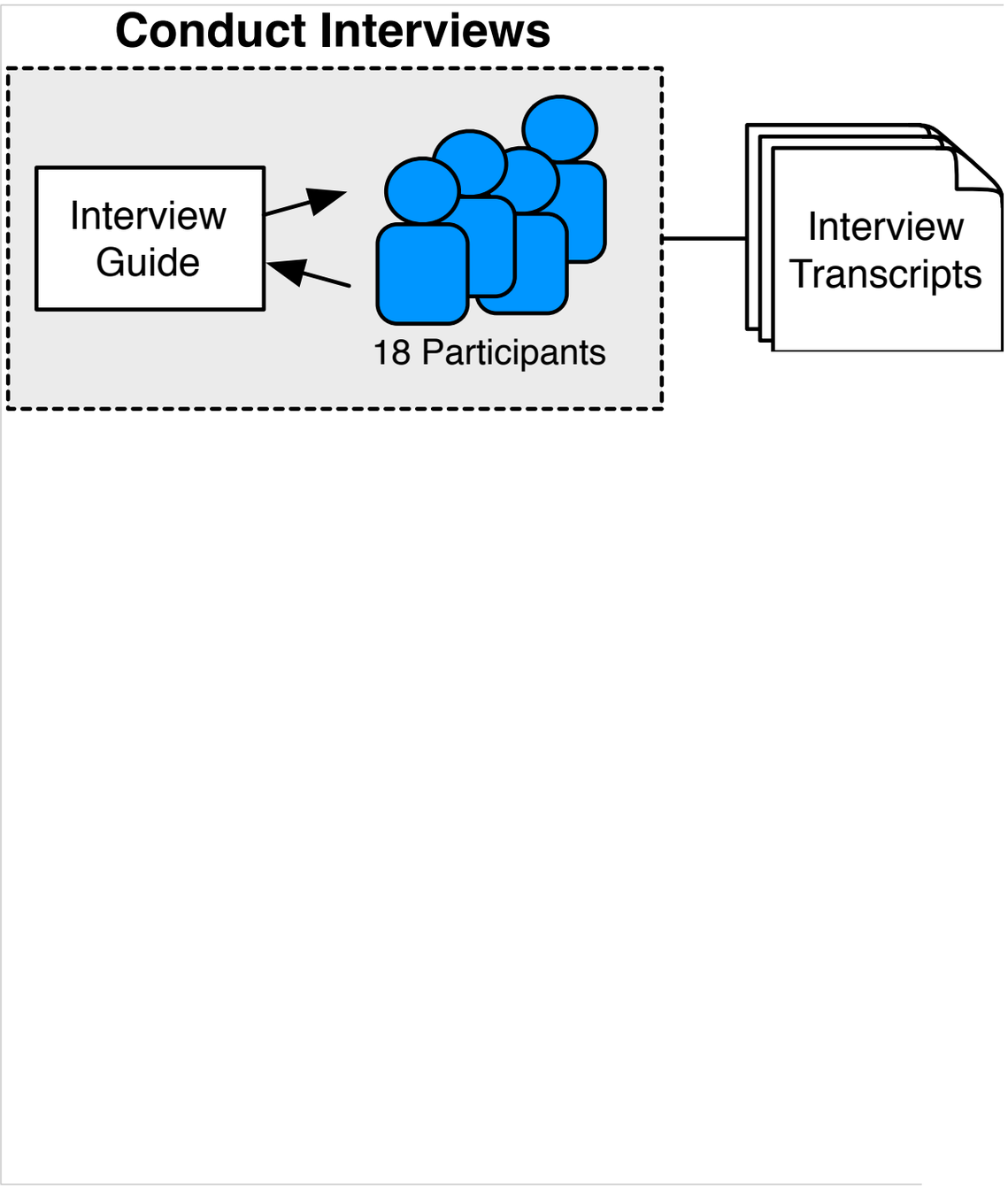
Irene Manotas[*], Christian Bird[†],
Rui Zhang[ß], David Shepherd[Ω], Ciera Jaspan[∂],
Caitlin Sadowski[∂], Lori Pollock[*], and James Clause[*]

*University of Delaware, †Microsoft Research, ß IBM Research-Almaden,
ΩABB Corporate Research, ∂Google, Inc.

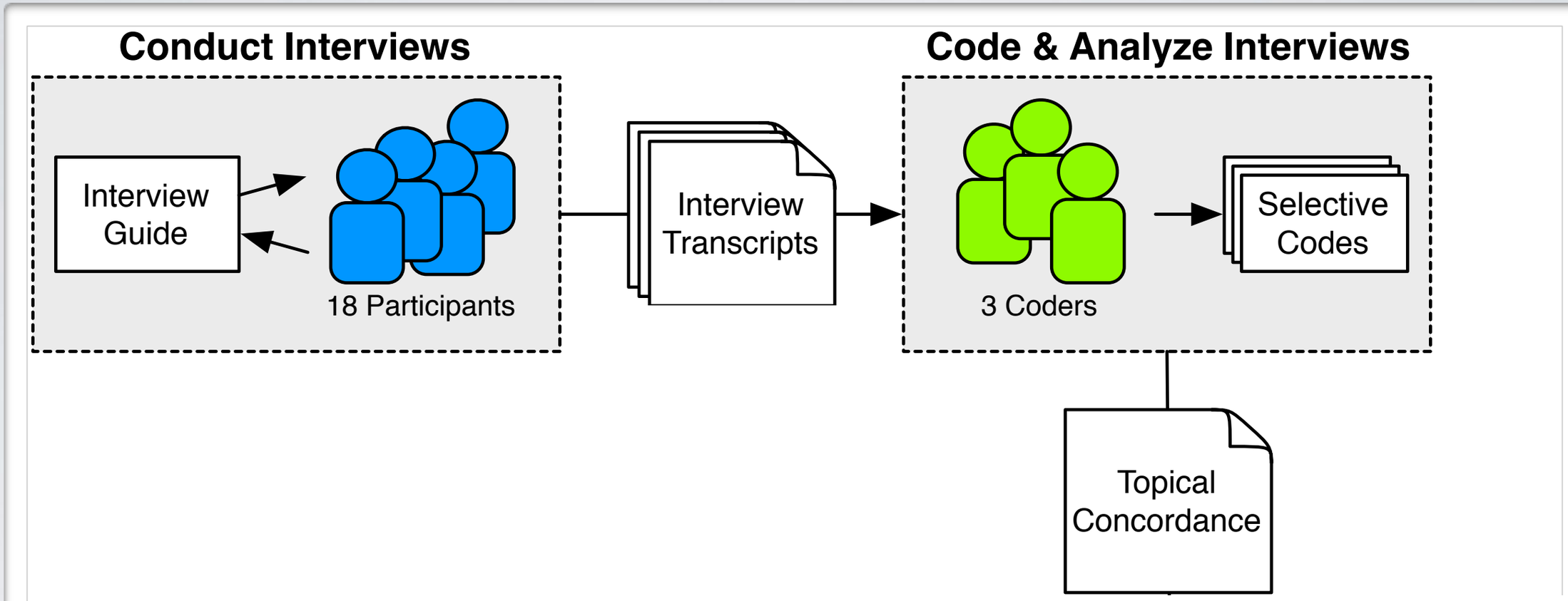
METHODOLOGY



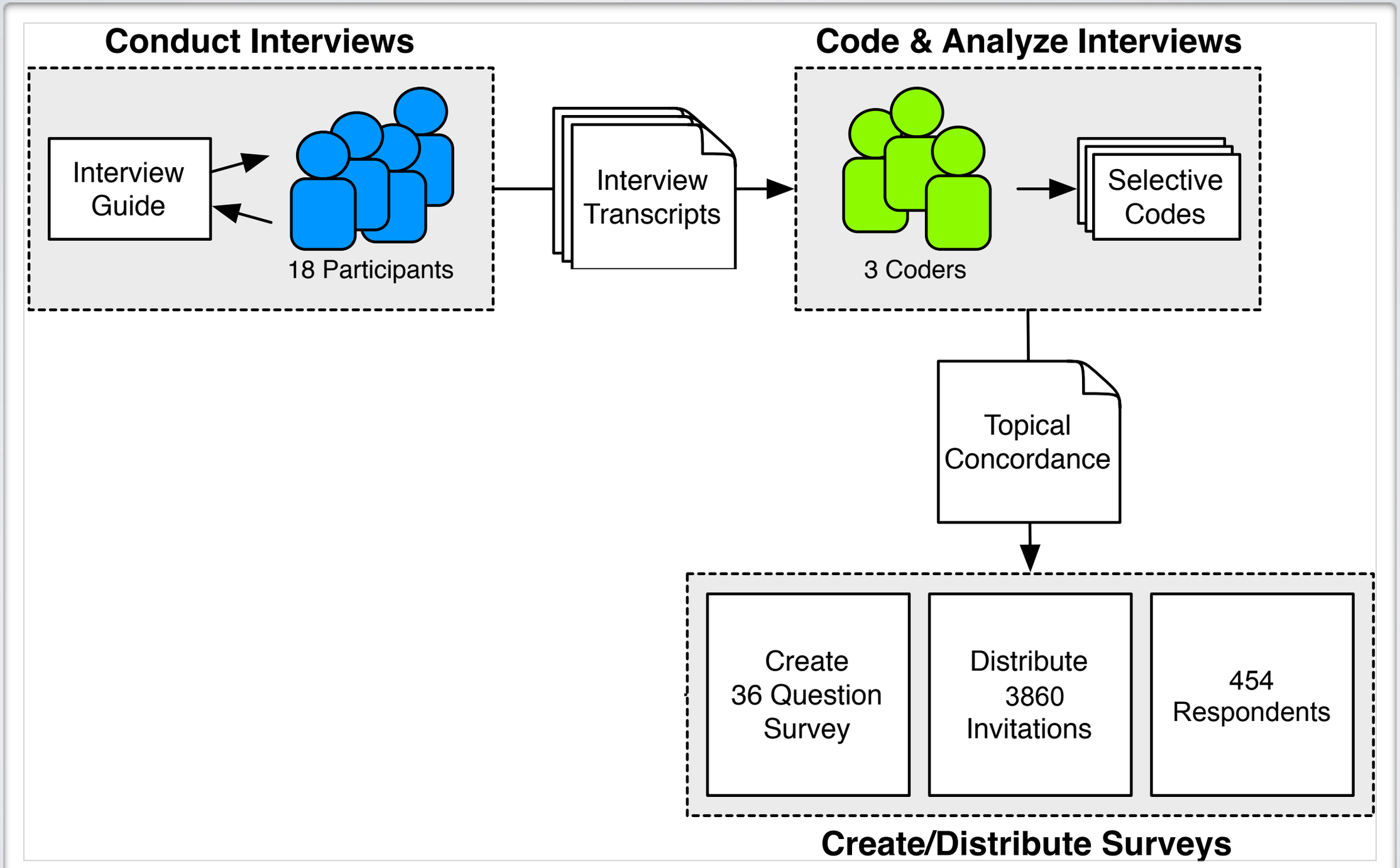
METHODOLOGY



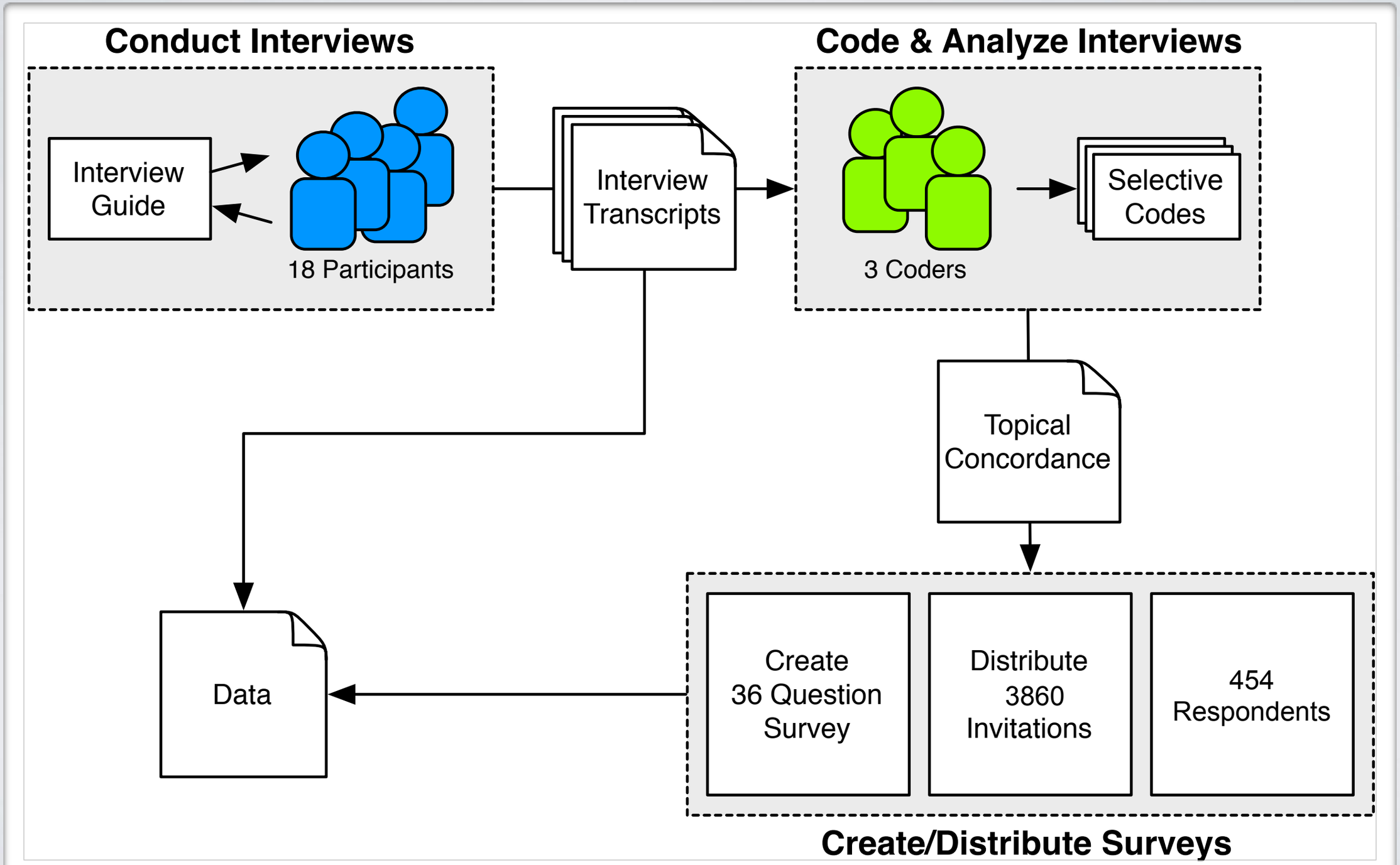
METHODOLOGY



METHODOLOGY

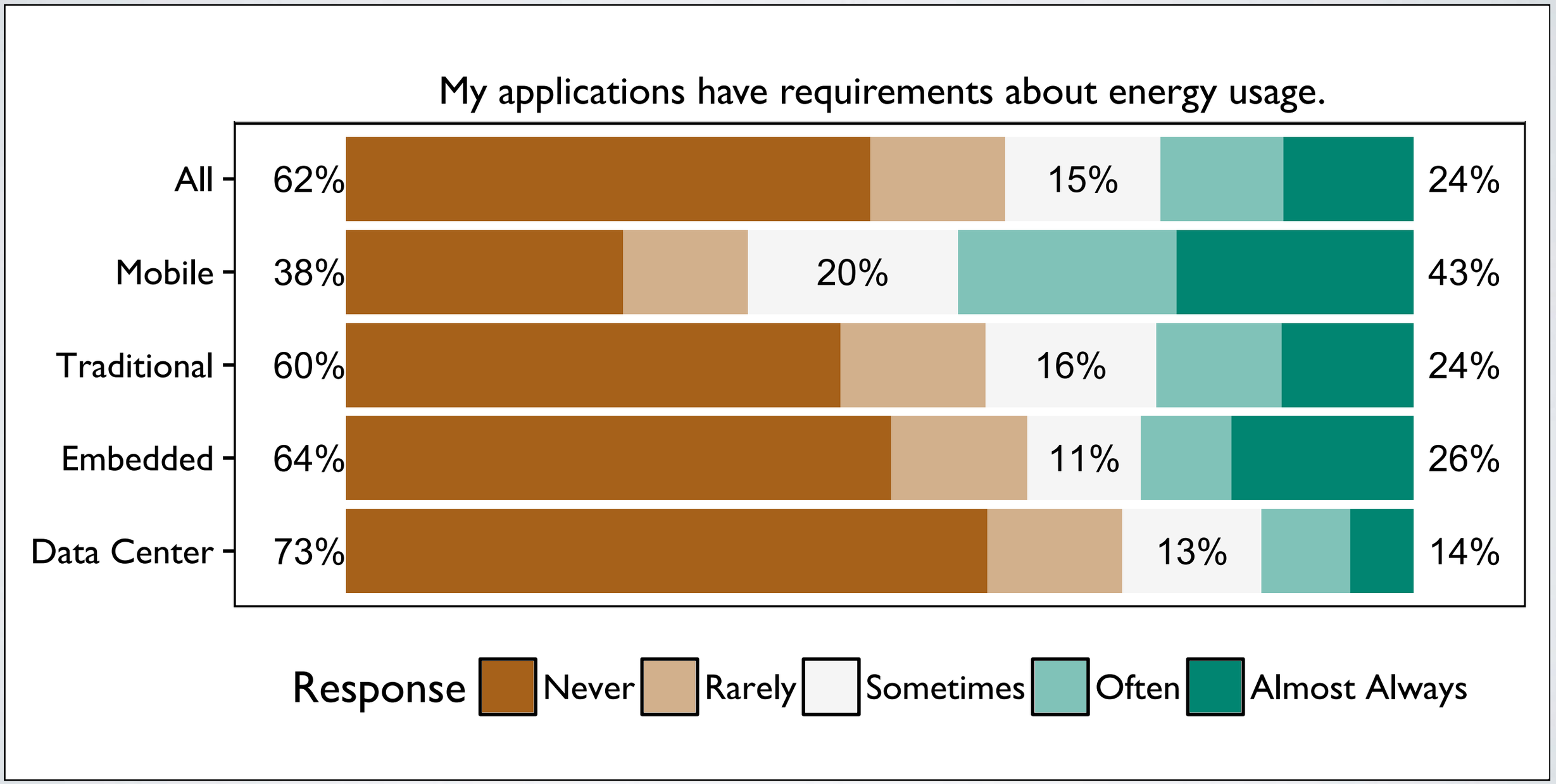


METHODOLOGY

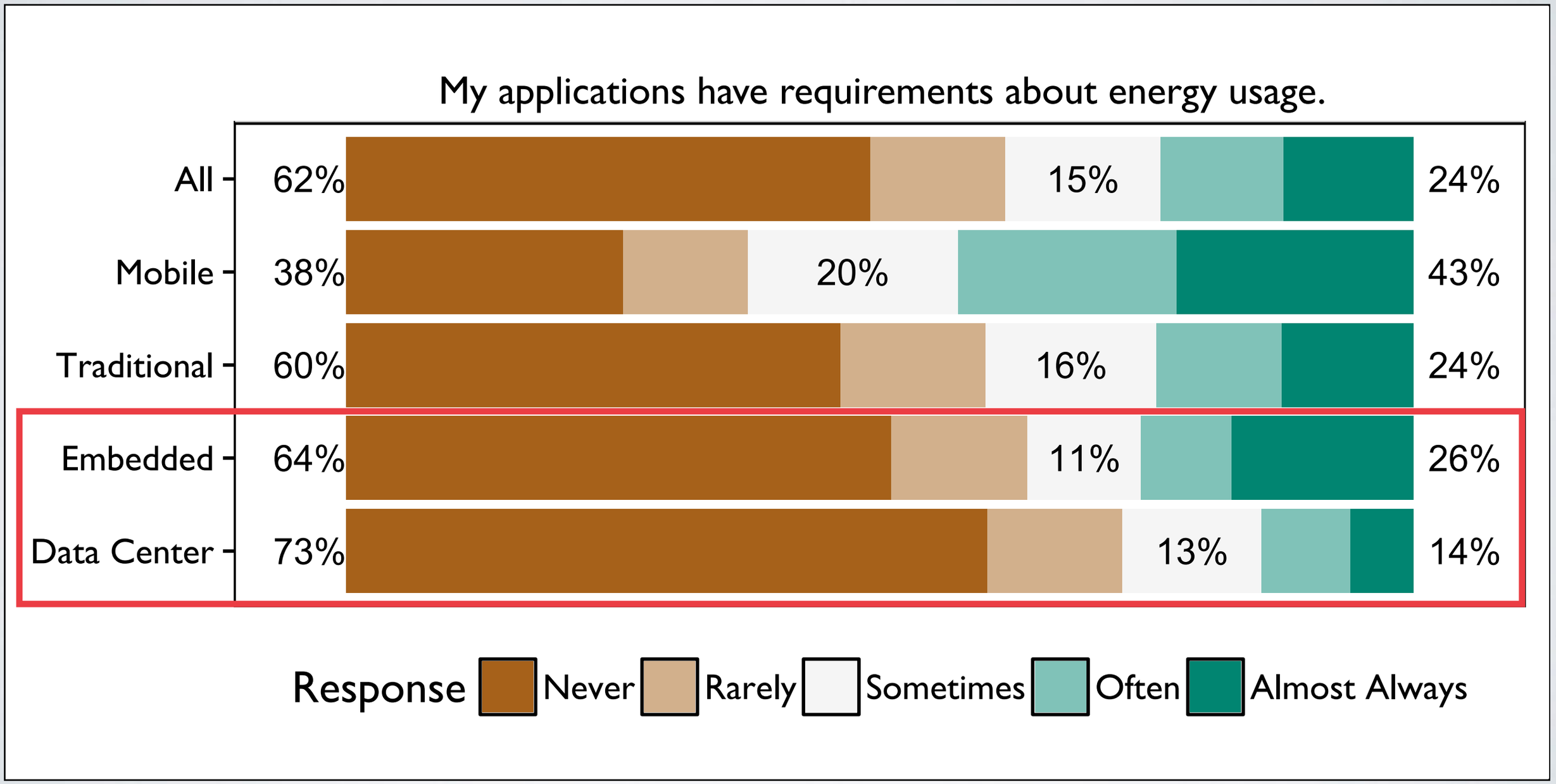


WHERE IS ENERGY USAGE A CONCERN?

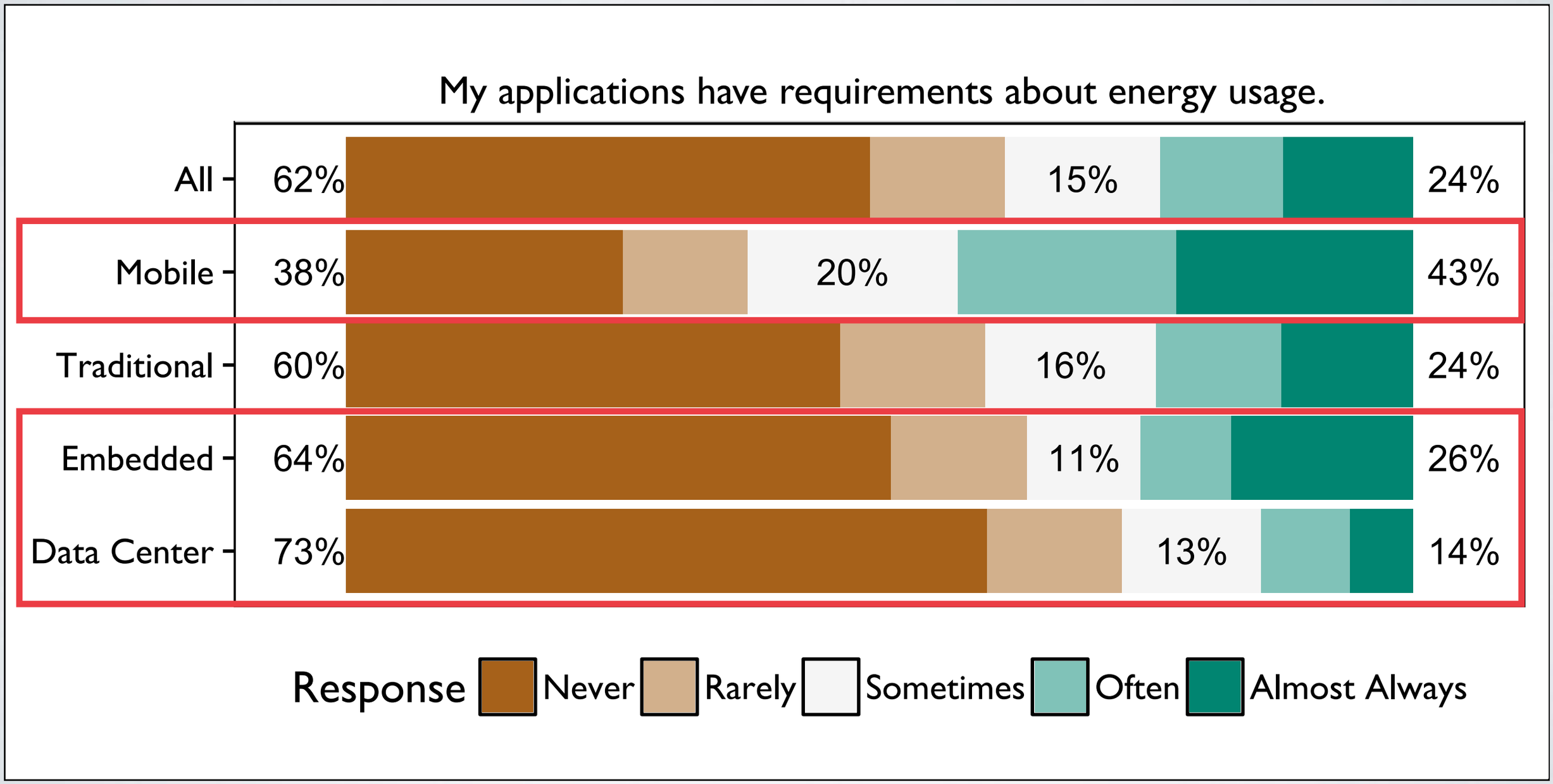
WHERE IS ENERGY USAGE A CONCERN?



WHERE IS ENERGY USAGE A CONCERN?



WHERE IS ENERGY USAGE A CONCERN?

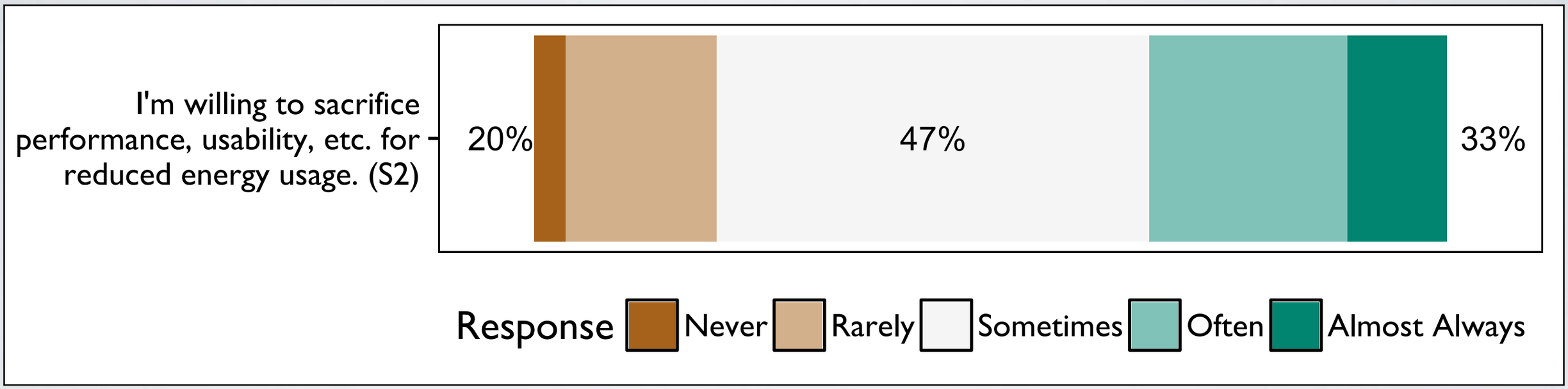


WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?



Practitioners care

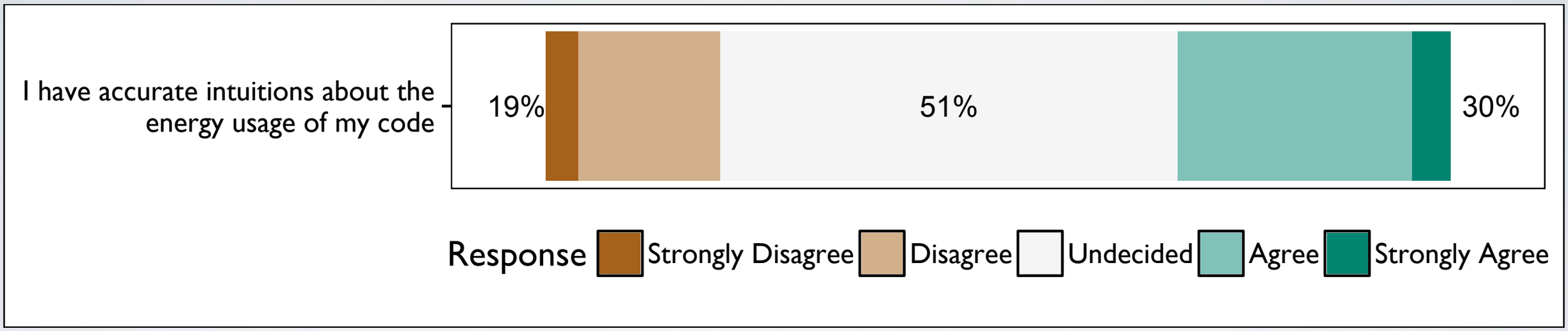
WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care, but they lack information

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?



"I care about memory usage, CPU usage, I understand those. I don't have the same intuition about energy."

Practitioners care, but they lack information

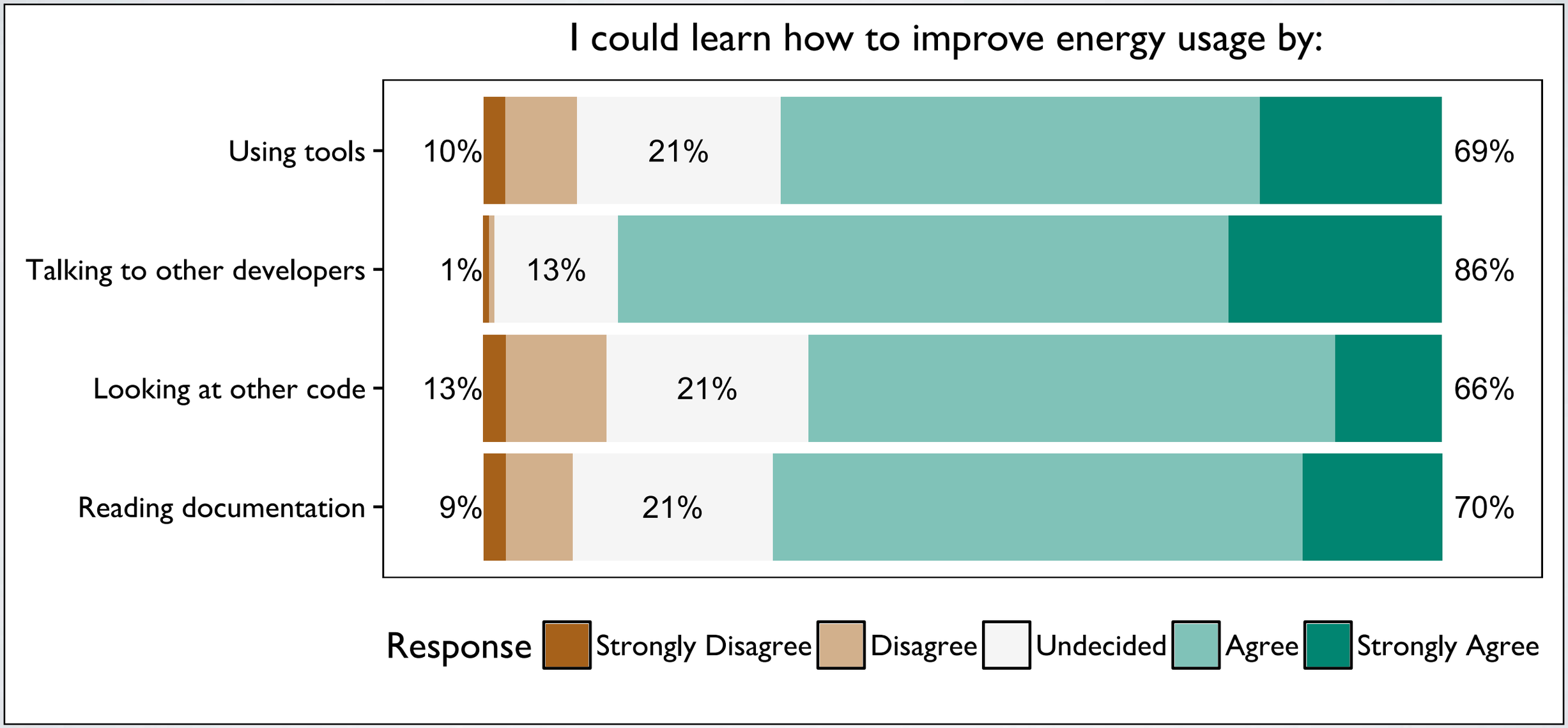
WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care, but they lack information

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care, but they lack information and tool support

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?



Practitioners care, but they lack information and tool support

WHAT ARE EXPERIENCED PRACTITIONERS' PERSPECTIVES?

Practitioners care, but they lack information and tool support

GIVING SOFTWARE ENGINEERS THE INFORMATION THEY NEED TO BE SUCCESSFUL

How Do Code Obfuscations Impact Energy Consumption?

Cagri Sahin, Philip Tornquist, Ryan McKenna,
Zachary Pearson, and James Clause

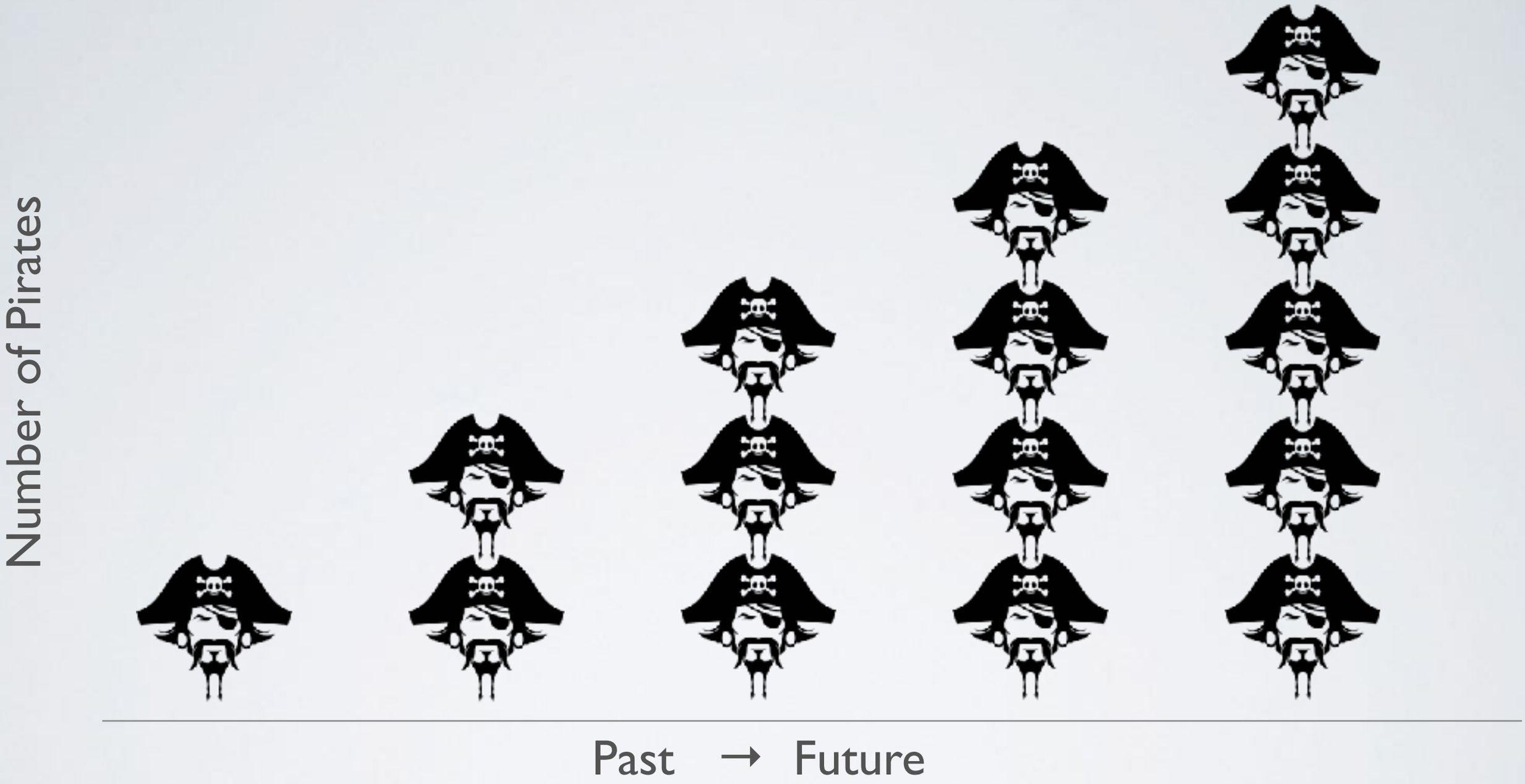
University of Delaware

INCREASING PIRACY RATES

Number of Pirates

Past → Future

INCREASING PIRACY RATES



INCREASING PIRACY RATES

- Overall, 40% of software is pirated resulting in losses of $63+ billion
- For mobile applications, piracy rates can approach 90%

CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

Pirates

Developers

CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

Pirates

Developers

Users

CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

Pirates

Developers

Users

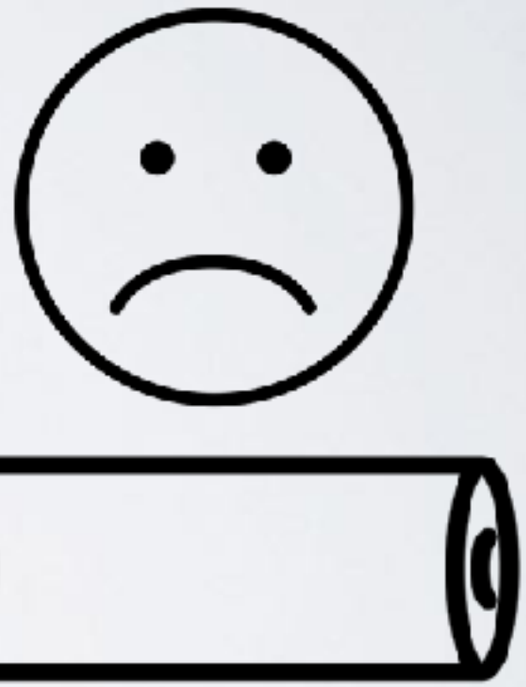
CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

Pirates

Developers

Users



CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

Pirates

Developers

Users

CODE OBFUSCATION

Semantics-preserving transformations that make code more difficult for humans (pirates) to understand.

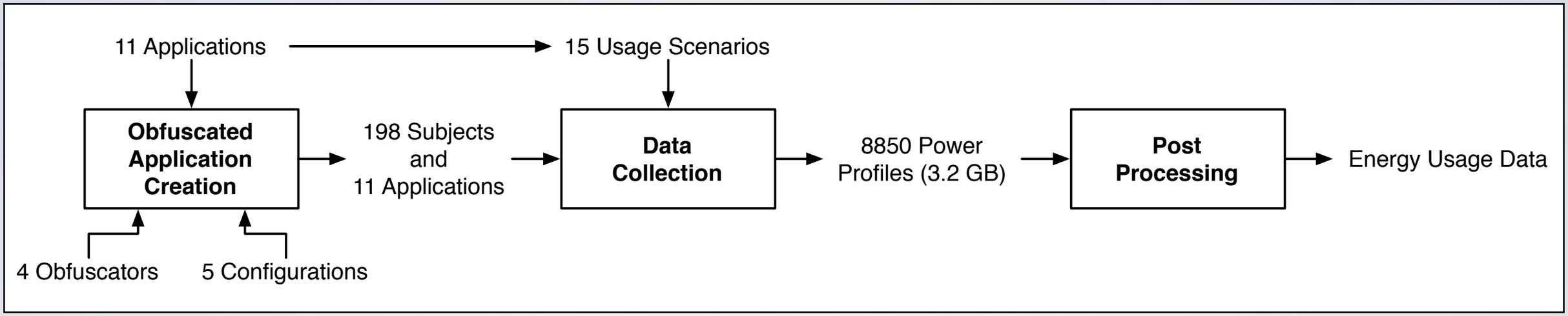
Pirates

Developers

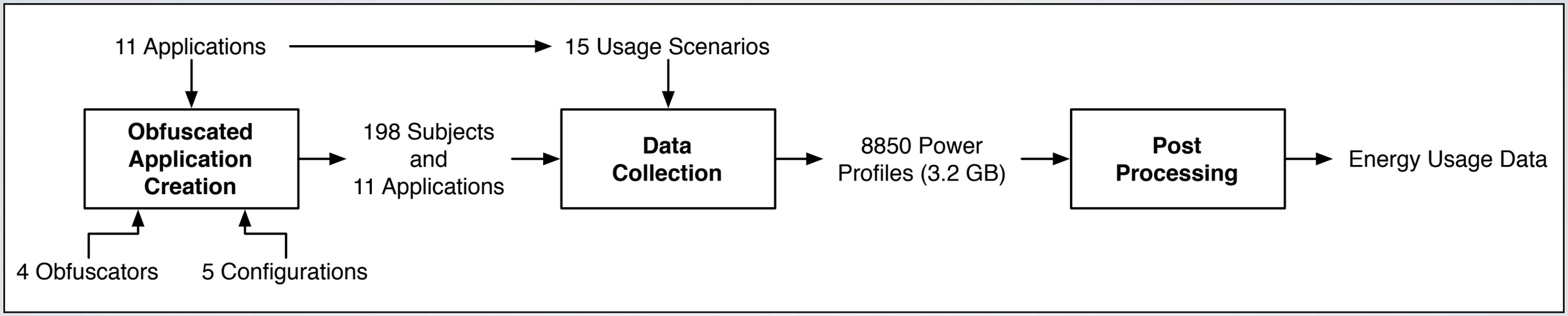
Users

Developers must balance protecting their applications and preserving battery power, but they lack the necessary information.

EMPIRICAL STUDY



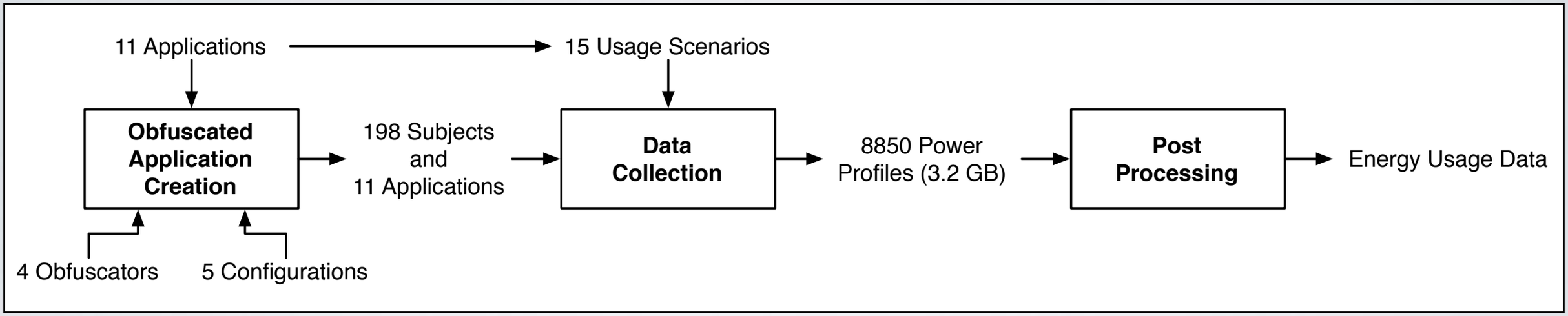
EMPIRICAL STUDY



Obfuscated Application Creation

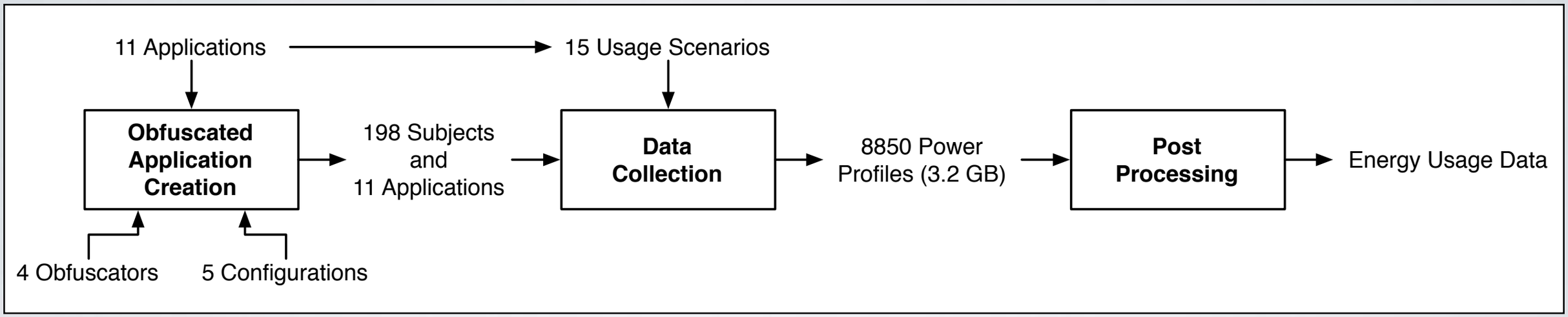
- Apply obfuscations to each application

EMPIRICAL STUDY



Obfuscated Application Creation	Data Collection
• Apply obfuscations to each application	• Replay each usage scenario • 30 repetitions for each obfuscated application and original application • 177+ hours of continuous execution time (over one week)

EMPIRICAL STUDY



Obfuscated Application Creation	Data Collection	Post Processing
• Apply obfuscations to each application	• Replay each usage scenario • 30 repetitions for each obfuscated application and original application • 177+ hours of continuous execution time (over one week)	• Discard samples before and after the execution • Convert power profiles to energy usage data

POWER MEASUREMENT

- Nexus 4-based custom energy measurement platform (EMP)
- Two Arduino Unos with current sensing boards
- Samples current (mA) and voltage (V) drawn from battery and USB
- No measurement overheads

ARE THE IMPACTS NOTICEABLE?

ARE THE IMPACTS NOTICEABLE?

1. Calculate the percentage of battery charge consumed by a scenario.

$$\%_{charge} = \frac{E}{3.8\,\mathrm{V}} \times \frac{1000}{2100\,\mathrm{mA\,h} \times 3600} \times 100$$

ARE THE IMPACTS NOTICEABLE?

1. Calculate the percentage of battery charge consumed by a scenario.

$$\%_{charge} = \frac{E}{3.8\,\mathrm{V}} \times \frac{1000}{2100\,\mathrm{mA\,h} \times 3600} \times 100$$

2. Calculate battery life (time needed to drain the battery).

$$t_{drain} = \frac{100\,\%}{\%_{charge}} \times D$$

- For our scenarios, battery life ranges from 3.0 to 5.3 hours.

ARE THE IMPACTS NOTICEABLE?

1. Calculate the percentage of battery charge consumed by a scenario.

$$\%_{charge} = \frac{E}{3.8\,\mathrm{V}} \times \frac{1000}{2100\,\mathrm{mA\,h} \times 3600} \times 100$$

2. Calculate battery life (time needed to drain the battery).

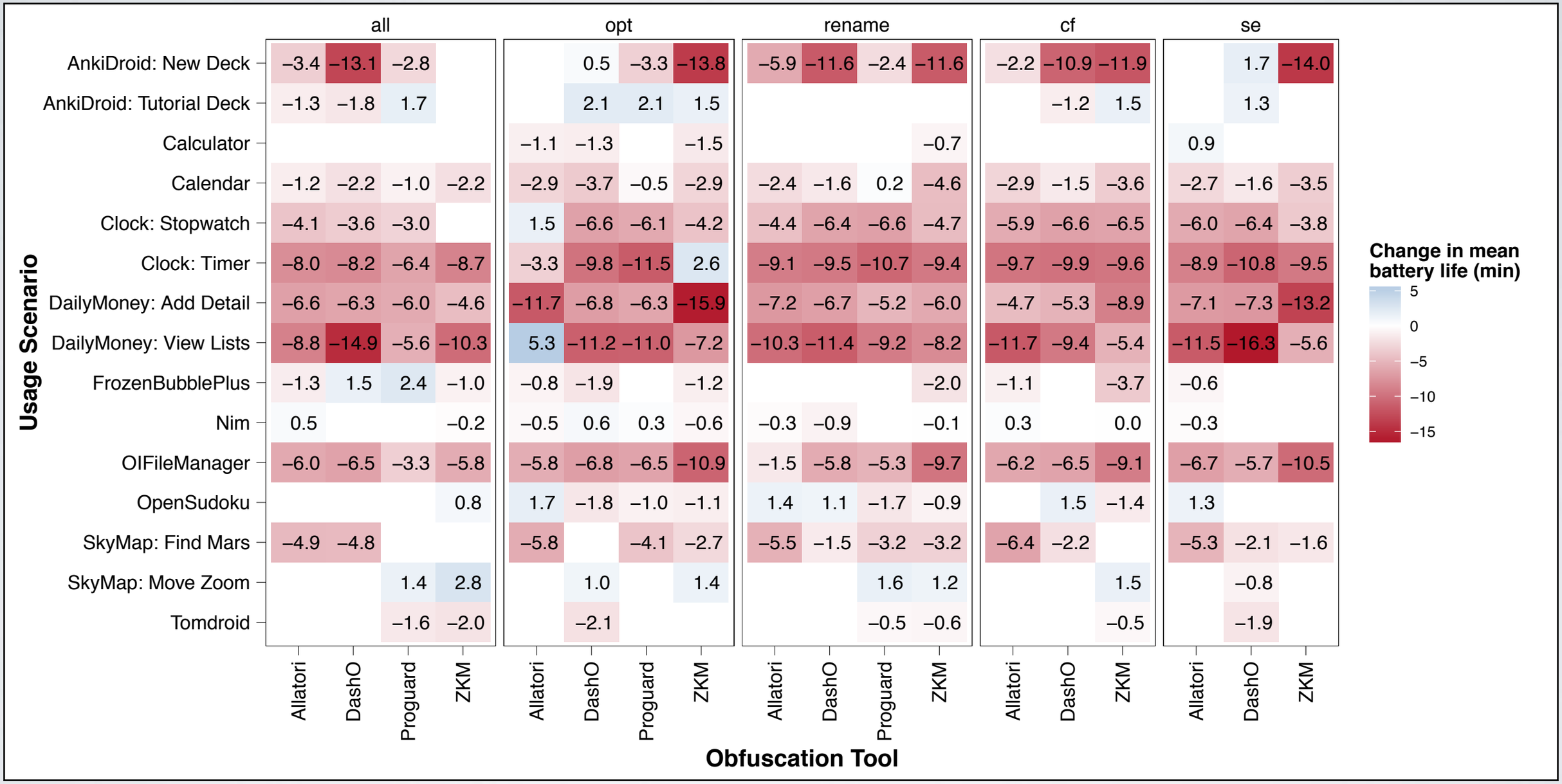
$$t_{drain} = \frac{100\,\%}{\%_{charge}} \times D$$

   - For our scenarios, battery life ranges from 3.0 to 5.3 hours.

3. Calculate the differences in battery life when using obfuscated versions instead of the original versions.

ARE THE IMPACTS NOTICEABLE?

Change in mean battery life when using an obfuscated version (wilcox, $p \leq 0.05$)



When scenarios are run continually, draining the battery from full to empty, differences in battery life range from -16 minutes to +5 minutes.

GIVING SOFTWARE ENGINEERS THE TOOLS THEY NEED TO BE SUCCESSFUL

SEEDS: A Software Engineer's Energy Optimization Decision Support Framework

Irene Manotas, Lori Pollock and James Clause

University of Delaware

THE SEEDS FRAMEWORK

1. Automatically apply changes to optimize applications' energy usage
2. Abstract away tedious system level concerns
3. Support different software engineering decisions

API IMPLEMENTATIONS

```
Collection x = new ??
```

Choose the most energy efficient implementation?

API IMPLEMENTATIONS

```
Collection x = new ??
```

Choose the most energy efficient implementation?

LinkedHashSet
TreeSet
HashSet
EnumSet
CopyOnWriteArraySet
⋮
~ 40

JCF

UnifiedSet
UnifiedMap
SetAdapter
MultiReaderFastList
InmutableUnifiedMap
⋮
~ 40

Goldman Sachs

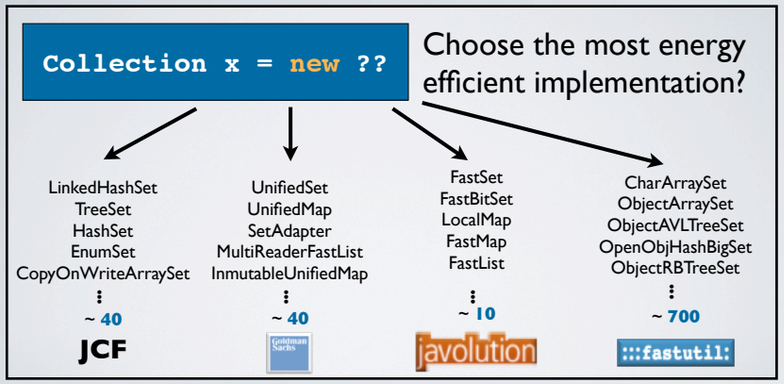
FastSet
FastBitSet
LocalMap
FastMap
FastList
⋮
~ 10

javolution

CharArraySet
ObjectArraySet
ObjectAVLTreeSet
OpenObjHashBigSet
ObjectRBTreeSet
⋮
~ 700

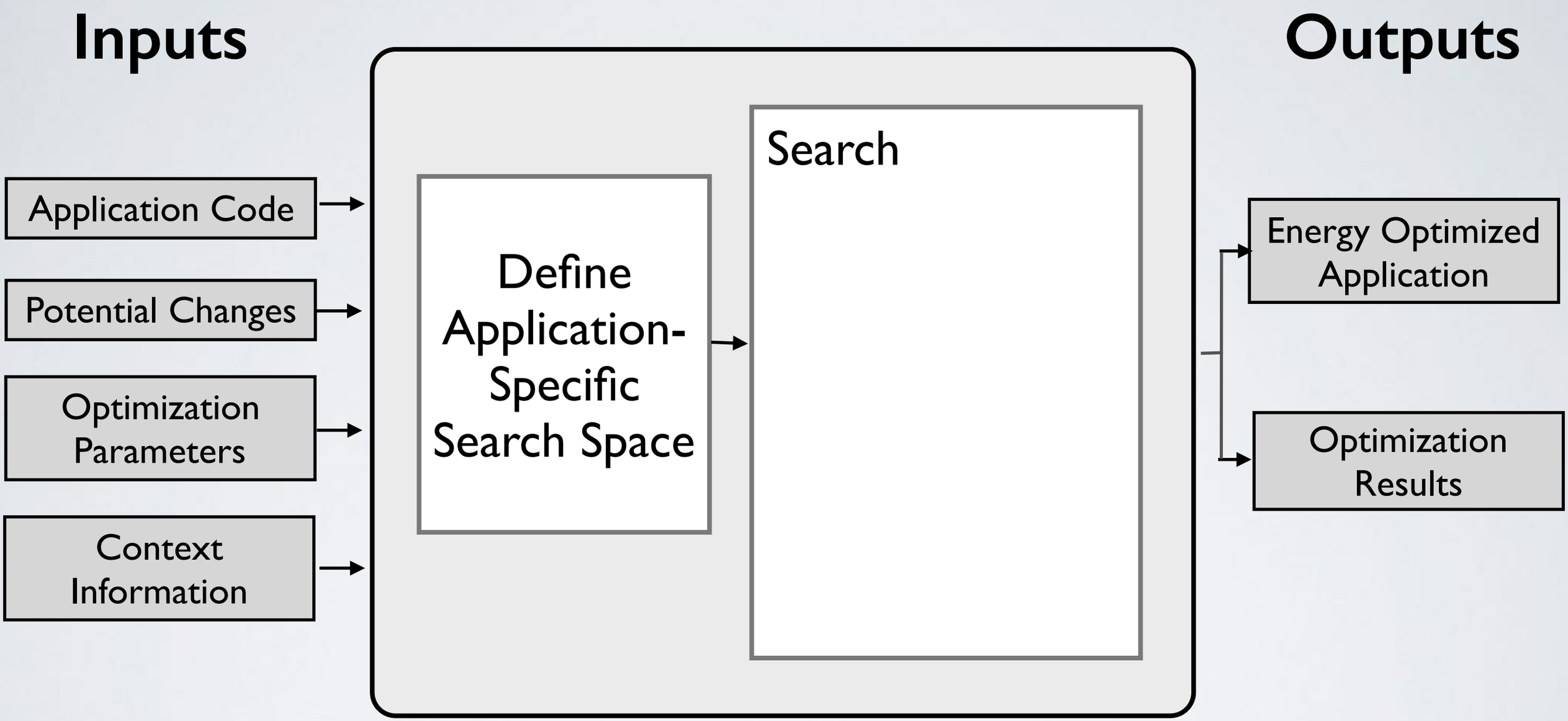
:::fastutil:

Hundreds of possibilities for each choice


Collection x = new ??
Choose the most energy efficient implementation?
LinkedHashSet
TreeSet
HashSet
EnumSet
CopyOnWriteArraySet
~ 40
JCF
UnifiedSet
UnifiedMap
SetAdapter
MultiReaderFastList
InmutableUnifiedMap
~ 40
FastSet
FastBitSet
LocalMap
FastMap
FastList
~ 10
javolution
CharArraySet
ObjectArraySet
ObjectAVLTreeSet
OpenObjHashBigSet
ObjectRBTreeSet
~ 700
:::fastutil:

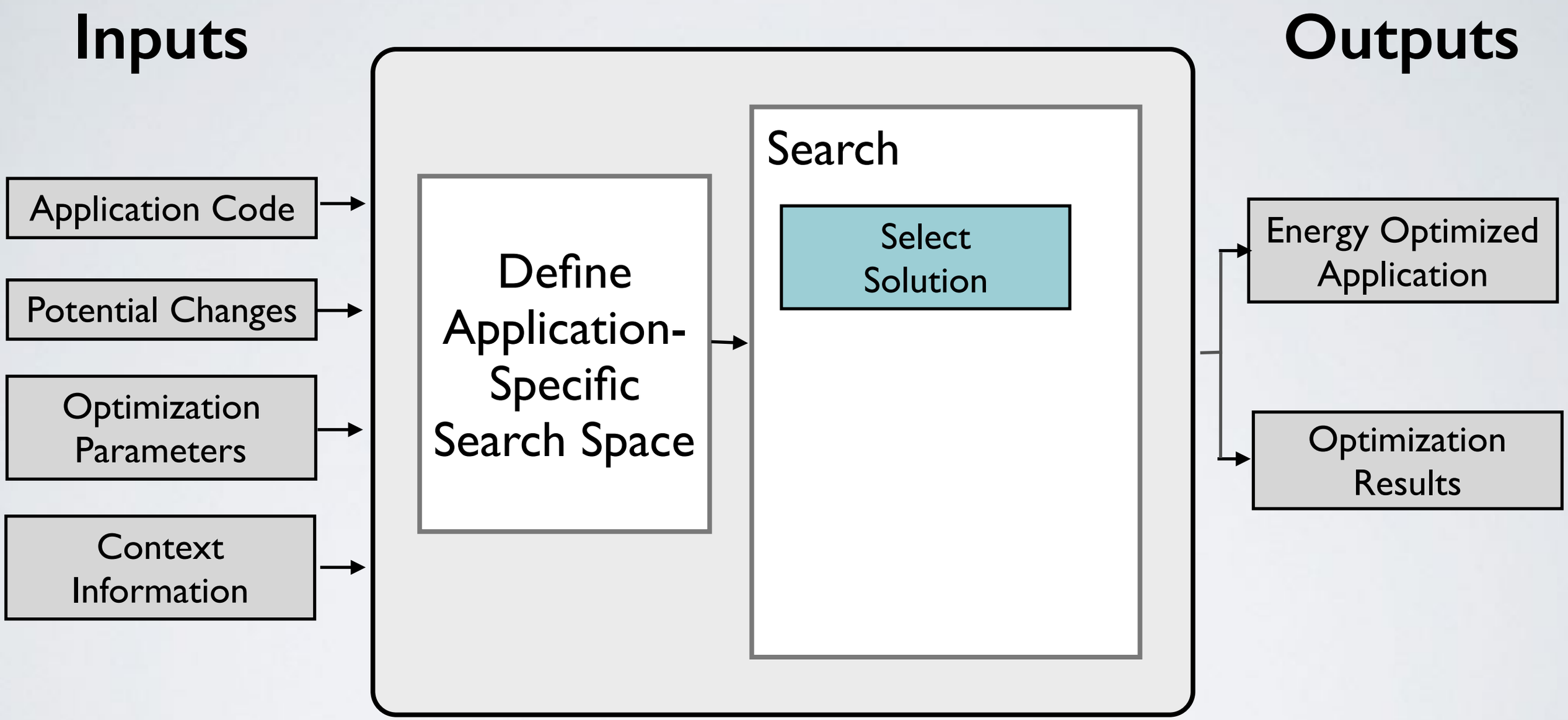
Hundreds of decisions points

SEEDS FRAMEWORK COMPONENTS



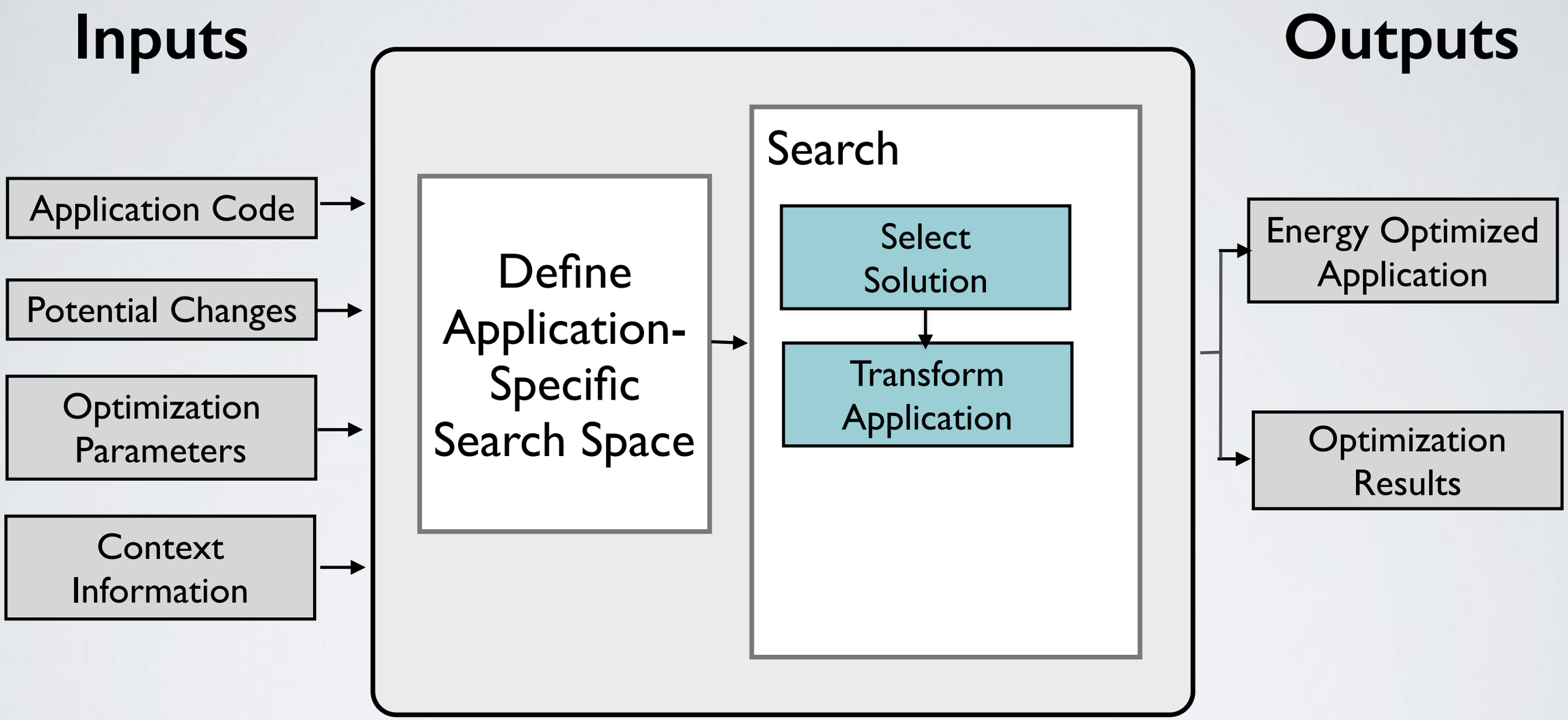
SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java applications.

SEEDS FRAMEWORK COMPONENTS



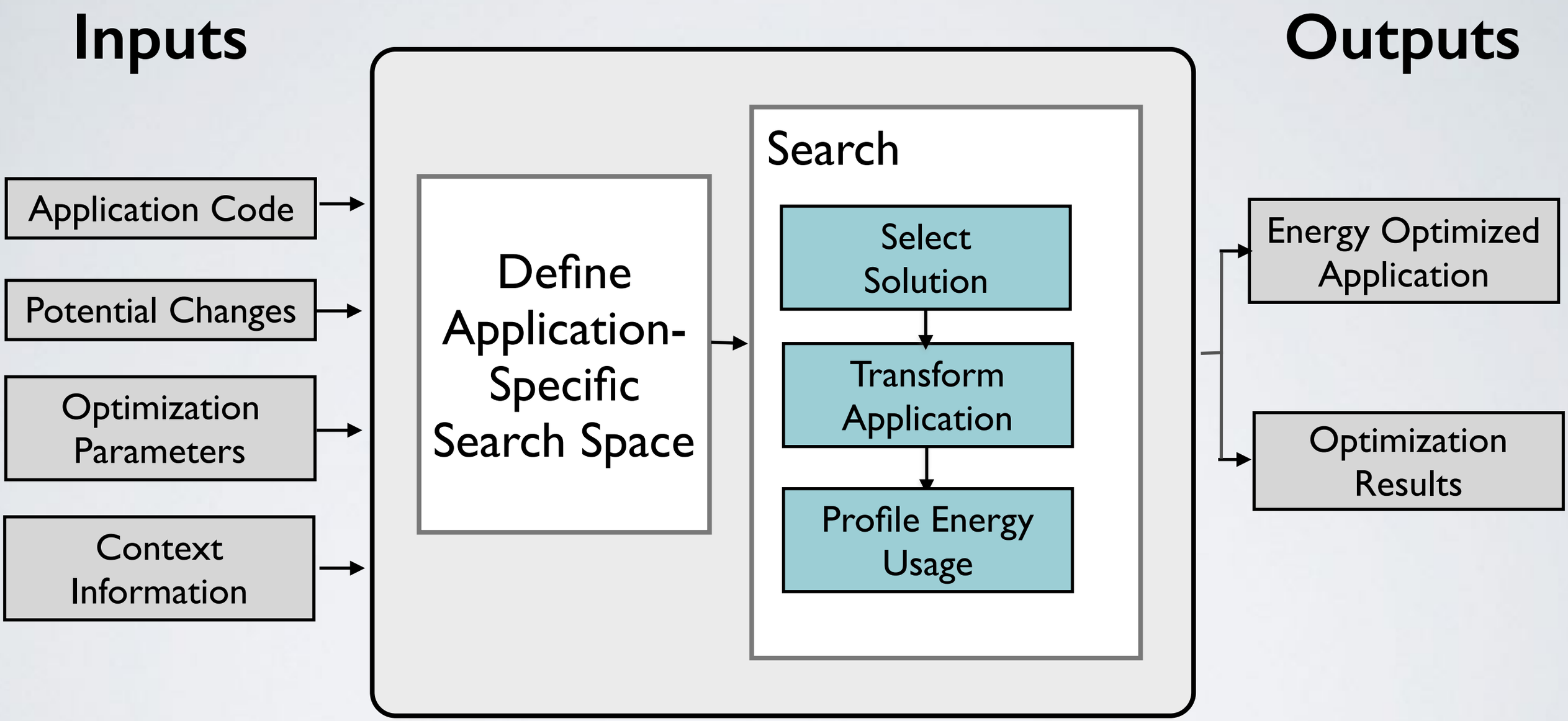
SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java applications.

SEEDS FRAMEWORK COMPONENTS



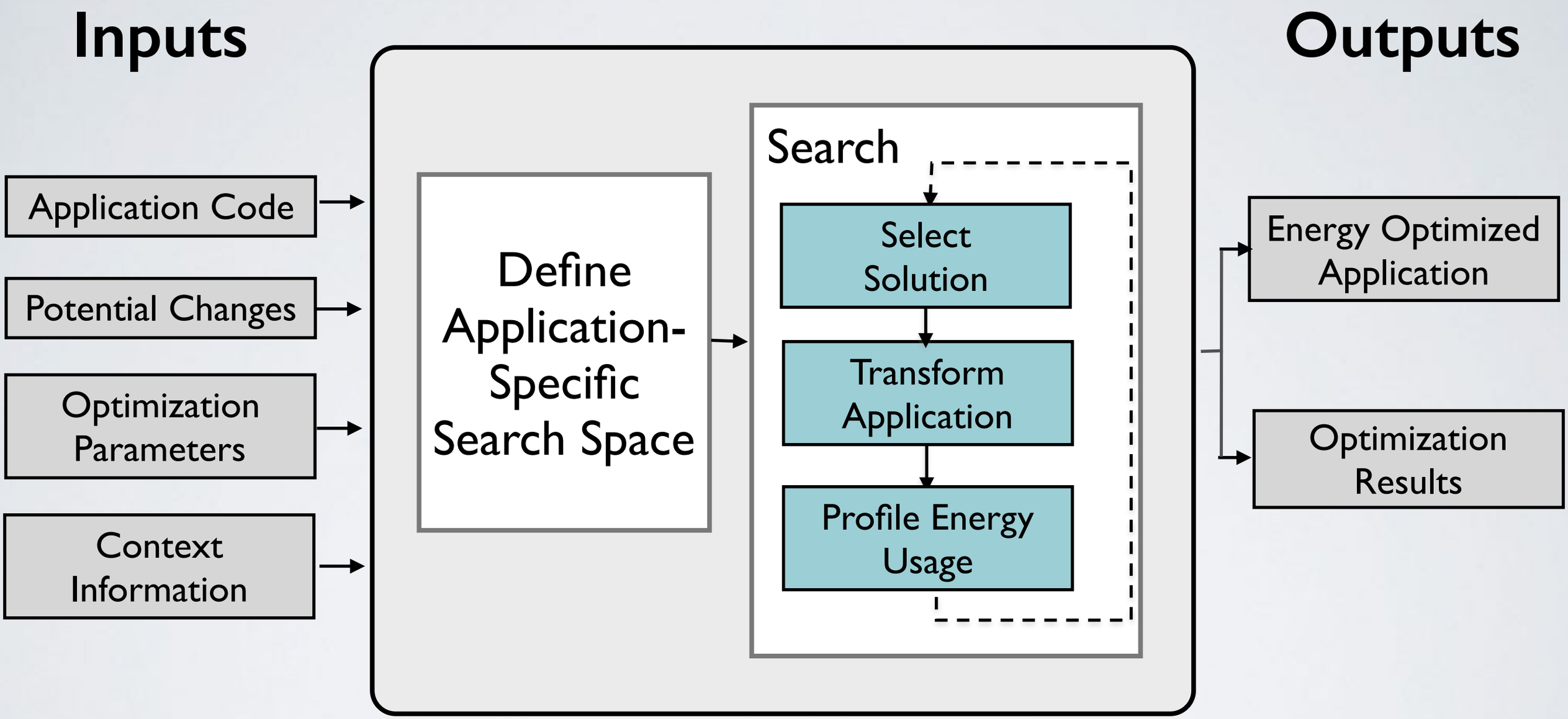
SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java applications.

SEEDS FRAMEWORK COMPONENTS



SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java applications.

SEEDS FRAMEWORK COMPONENTS



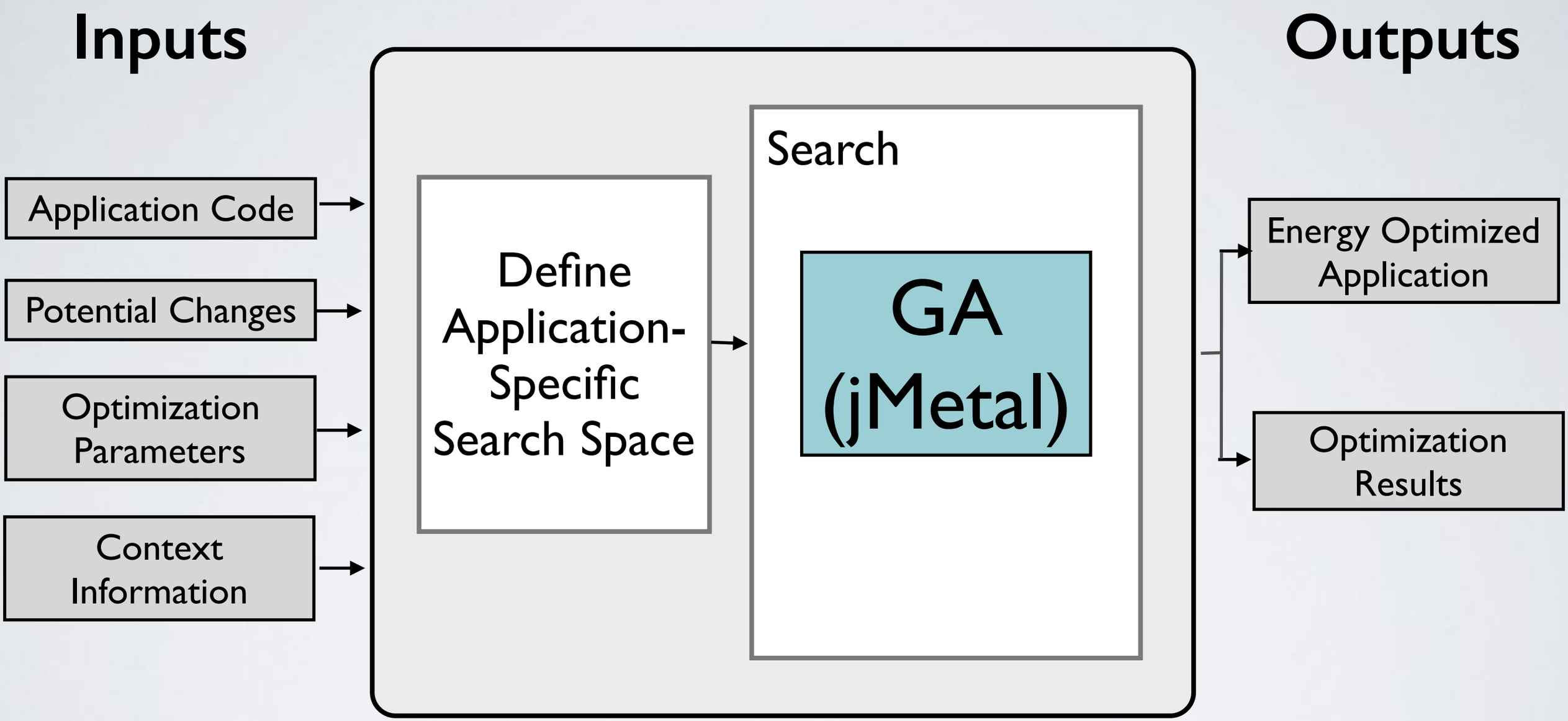
SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java applications.

EFFECTIVENESS OF SEEDS_API

Application	% Improvement
Barbecue	17
Jdepend	6
Apache-xml-security	5
JodaTime	9
Commons-lang	13
Commons-beanutils	–
Commons-cli	2

Extremely simplistic search strategy:
try each alternative API at each location, individually

GA-BASED SEEDS FRAMEWORK



EFFECTIVENESS OF (JMETAL) SEEDS_API

Application	% Improvement
Barbecue	~~17~~ 18
JodaTime	~~9~~ 9
Commons-cli	~~2~~ 3

1. Single objective, generational GA (100 generations, 50 individuals)
2. Integer array representation of individuals
3. Default selection, mutation, and crossover

OPEN CHALLENGES

OPEN CHALLENGES

1. Many GA algorithms and configuration options, excessive execution times make exploration prohibitive.

OPEN CHALLENGES

1. Many GA algorithms and configuration options, excessive execution times make exploration prohibitive.
2. Rugged fitness landscape (epistasis)

OPEN CHALLENGES

1. Many GA algorithms and configuration options, excessive execution times make exploration prohibitive.
2. Rugged fitness landscape (epistasis)
3. Lack of support for automatically applying changes

OPEN CHALLENGES

1. Many GA algorithms and configuration options, excessive execution times make exploration prohibitive.
2. Rugged fitness landscape (epistasis)
3. Lack of support for automatically applying changes
4. Fitness value difficult to calculate reliably