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

Software Engineer

- Source Code
- Compiler
- Operating System
- Hardware (cpu, disk, etc.)
REDUCING ENERGY USAGE

Software Engineer

Source Code

Compiler

Operating System

Hardware cpu, disk, etc.

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

Software Engineer

Source Code

Compiler

Operating System

Hardware
cpu, disk, etc.
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‡, David ShepherdΩ, Ciera Jaspan‡,
Caitlin Sadowski‡, Lori Pollock*, and James Clause*

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

Conduct Interviews

- Interview Guide
- 18 Participants
METHODOLOGY

Conduct Interviews

- Interview Guide
- 18 Participants

Create/Distribute Surveys

- Distribute 1500 Invitations
- Create 36 Question Survey

Distribute

- 247 Respondents

Code & Analyze Interviews

- 14 Codes
- 3 Coders

Interview Transcripts

- Topical Concordance
- 454 Respondents
- 3860 Selective
METHODOLOGY

Conduct Interviews

- Interview Guide
- 18 Participants

Code & Analyze Interviews

- Interview Transcripts
- 3 Coders
- Selective Codes
- Topical Concordance

36 Question Survey
1500 Invitations
247 Respondents
14 Codes
454 Respondents
3860 Selective Codes
**METHODOLOGY**

---

### Conduct Interviews
- **Interview Guide**
- **18 Participants**

### Create/Distribute Surveys
- **Create 36 Question Survey**
- **Distribute 3860 Invitations**
- **454 Respondents**

### Code & Analyze Interviews
- **Interview Transcripts**
- **3 Coders**
- **Topical Concordance**
- **Selective Codes**

---

Create/Distribute Surveys
METHODOLOGY

**Conduct Interviews**
- Interview Guide
- 18 Participants

**Code & Analyze Interviews**
- Interview Transcripts
- 3 Coders

**Create/Distribute Surveys**
- Create 36 Question Survey
- Distribute 3860 Invitations
- 454 Respondents

**Topical Concordance**
- 454 Respondents

**Data**
- 247 Respondents
- 3860 Invitations
- 36 Question Survey
WHERE IS ENERGY USAGE A CONCERN?
WHERE IS ENERGY USAGE A CONCERN?

My applications have requirements about energy usage.

- **All**: 62% (Never 24%, Rarely 14%, Sometimes 11%, Often 13%, Almost Always 14%)
- **Mobile**: 38% (Never 43%, Rarely 26%, Sometimes 24%, Often 24%, Almost Always 14%)
- **Traditional**: 60% (Never 24%, Rarely 26%, Sometimes 24%, Often 24%, Almost Always 14%)
- **Embedded**: 64% (Never 26%, Rarely 24%, Sometimes 24%, Often 24%, Almost Always 14%)
- **Data Center**: 73% (Never 14%, Rarely 13%, Sometimes 13%, Often 13%, Almost Always 14%)

Response: **Never** - **Rarely** - **Sometimes** - **Often** - **Almost Always**
My applications have requirements about energy usage. (S1)

WHERE IS ENERGY USAGE A CONCERN?

<table>
<thead>
<tr>
<th>Category</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Almost Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>24%</td>
<td>24%</td>
<td>14%</td>
<td>26%</td>
<td>24%</td>
</tr>
<tr>
<td>Mobile</td>
<td>43%</td>
<td>26%</td>
<td>11%</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td>Traditional</td>
<td>24%</td>
<td>16%</td>
<td>11%</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Embedded</td>
<td>26%</td>
<td>13%</td>
<td>13%</td>
<td>11%</td>
<td>16%</td>
</tr>
<tr>
<td>Data Center</td>
<td>14%</td>
<td>13%</td>
<td>13%</td>
<td>11%</td>
<td>20%</td>
</tr>
</tbody>
</table>
WHERE IS ENERGY USAGE A CONCERN?

- **My applications have requirements about energy usage.**
  - **All**: 62% Never, 15% Rarely, 13% Sometimes, 20% Often, 16% Almost Always
  - **Mobile**: 38% Never, 20% Rarely, 11% Sometimes, 26% Often, 24% Almost Always
  - **Traditional**: 60% Never, 16% Rarely, 13% Sometimes, 11% Often, 24% Almost Always
  - **Embedded**: 64% Never, 11% Rarely, 13% Sometimes, 26% Often, 14% Almost Always
  - **Data Center**: 73% Never, 13% Rarely, 14% Sometimes, 43% Often, 24% Almost Always

**Response**

- Never
- Rarely
- Sometimes
- Often
- Almost Always
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?

I'm willing to sacrifice performance, usability, etc. for reduced energy usage. (S2)

- 20% Never
- 47% Rarely
- 33% Sometimes

Practitioners care
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?

Practitioners care, but they lack information
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?

I have accurate intuitions about the energy usage of my code

<table>
<thead>
<tr>
<th>Response</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Undecided</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>19%</td>
<td>51%</td>
<td>30%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“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?

I could learn how to improve energy usage by:

- Using tools: 10% Strongly Disagree, 21% Disagree, 69% Agree, 69% Strongly Agree
- Talking to other developers: 1% Strongly Disagree, 13% Disagree, 86% Agree, 86% Strongly Agree
- Looking at other code: 13% Strongly Disagree, 21% Disagree, 66% Agree, 66% Strongly Agree
- Reading documentation: 9% Strongly Disagree, 21% Disagree, 70% Agree, 70% Strongly Agree

Practitioners care, but they lack information and tool support.
WHAT ARE EXPERIENCED PRACTITIONERS’ PERSPECTIVES?

Practitioners care, but they lack information and tool support
How Do Code Obfuscations Impact Energy Consumption?

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

University of Delaware
INCREASING PIRACY RATES
INCREASING PIRACY RATES

Number of Pirates

Past → Future
• 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.
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
- 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.
Developers must balance protecting their applications and preserving battery power, but they lack the necessary information.

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

11 Applications

Obfuscated Application Creation

198 Subjects and 11 Applications

Data Collection

8850 Power Profiles (3.2 GB)

Post Processing

Energy Usage Data

15 Usage Scenarios

4 Obfuscators 5 Configurations

11 Applications
EMPIRICAL STUDY

Obfuscated Application Creation

- Apply obfuscations to each application
EMPIRICAL STUDY

**Obfuscated Application Creation**
- Apply obfuscations to each application
- 4 Obfuscators
- 5 Configurations

**Data Collection**
- Replay each usage scenario
- 30 repetitions for each obfuscated application and original application
- 177+ hours of continuous execution time (over one week)
- 198 Subjects and 11 Applications

**Post Processing**
- 8850 Power Profiles (3.2 GB)
- Energy Usage Data
**EMPIRICAL STUDY**

- **Obfuscated Application Creation**
  - 11 Applications
  - 4 Obfuscators
  - 5 Configurations

- **198 Subjects and 11 Applications**

- **15 Usage Scenarios**

- **Data Collection**
  - 8850 Power Profiles (3.2 GB)
  - 30 repetitions for each obfuscated application and original application
  - 177+ hours of continuous execution time (over one week)

- **Post Processing**
  - Discard samples before and after the execution
  - Convert power profiles to energy usage data

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

\[
\%_{\text{charge}} = \frac{E}{3.8 \, \text{V}} \times \frac{1000}{2100 \, \text{mA h} \times 3600} \times 100
\]
1. Calculate the percentage of battery charge consumed by a scenario.

\[
\%_{\text{charge}} = \frac{E}{3.8 \text{ V}} \times \frac{1000}{2100 \text{ mA h} \times 3600} \times 100
\]

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

\[
t_{\text{drain}} = \frac{100 \%}{\%_{\text{charge}}} \times D
\]

- For our scenarios, battery life ranges from 3.0 to 5.3 hours.
1. Calculate the percentage of battery charge consumed by a scenario.

\[
\%_{\text{charge}} = \frac{E}{3.8 \text{ V}} \times \frac{1000}{2100 \text{ mA h} \times 3600} \times 100
\]

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

\[
t_{\text{drain}} = \frac{100 \%}{\%_{\text{charge}}} \times D
\]

• 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
Choose the most energy efficient implementation?

Collection x = new ??
Choose the most energy efficient implementation?

Collection \( x = \text{new ??} \)

- LinkedHashSet
- TreeSet
- HashSet
- EnumSet
- CopyOnWriteArraySet
- UnifiedSet
- UnifiedMap
- SetAdapter
- MultiReaderFastList
- InmutableUnifiedMap
- FastSet
- FastBitSet
- LocalMap
- FastMap
- FastList
- CharArraySet
- ObjectArraySet
- ObjectAVLTreeSet
- OpenObjHashBigSet
- ObjectRBTreeSet

Hundreds of possibilities for each choice
How can developers help?

Choose the most energy efficient implementation?

Collection x = new ??

- LinkedListSet
- HashSet
- EnumSet
- CopyOnWriteArraySet
- JCF

- UnifiedSet
- UnifiedMap
- SetAdapter
- MultiReaderFastList
- ImmutableUnifiedMap

- FastSet
- FastBitSet
- LocalMap
- FastMap
- FastList
- JCF
- Jevolution
- FastList

- CharSet
- ObjectArraySet
- ObjectAVLTreeSet
- OpenObjHashBigSet
- ObjectRBTreeSet

- JCF
- Jevolution
- FastList

- ~40
- ~10
- ~700
Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?

Collection x = new ?? Choose the most energy efficient implementation?
SEEDS FRAMEWORK COMPONENTS

Inputs
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search

Outputs
- Energy Optimized Application
- Optimization Results

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

Inputs
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search
- Select Solution

Outputs
- Energy Optimized Application
- Optimization Results

SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java application.
SEEDS FRAMEWORK COMPONENTS

Inputs:
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search
- Select Solution
- Transform Application

Outputs:
- Energy Optimized Application
- Optimization Results

SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java application.
SEEDS FRAMEWORK COMPONENTS

Inputs
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search
- Select Solution
- Transform Application
- Profile Energy Usage

Outputs
- Energy Optimized Application
- Optimization Results

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

Inputs
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search
- Select Solution
- Transform Application
- Profile Energy Usage

Outputs
- Energy Optimized Application
- Optimization Results

SEEDS_api supports the selection of Library implementations to optimize the energy usage of a Java application.
EFFECTIVENESS OF SEEDS_API

<table>
<thead>
<tr>
<th>Application</th>
<th>% Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbecue</td>
<td>17</td>
</tr>
<tr>
<td>Jdepend</td>
<td>6</td>
</tr>
<tr>
<td>Apache-xml-security</td>
<td>5</td>
</tr>
<tr>
<td>JodaTime</td>
<td>9</td>
</tr>
<tr>
<td>Commons-lang</td>
<td>13</td>
</tr>
<tr>
<td>Commons-beanutils</td>
<td>-</td>
</tr>
<tr>
<td>Commons-cli</td>
<td>2</td>
</tr>
</tbody>
</table>

 Extremely simplistic search strategy:
try each alternative API at each location, individually
GA-BASED SEEDS FRAMEWORK

Inputs
- Application Code
- Potential Changes
- Optimization Parameters
- Context Information

Define Application-Specific Search Space

Search

GA (jMetal)

Outputs
- Energy Optimized Application
- Optimization Results
## EFFECTIVENESS OF (JMETAL) SEEDS_API

<table>
<thead>
<tr>
<th>Application</th>
<th>% Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbecue</td>
<td>17 18</td>
</tr>
<tr>
<td>JodaTime</td>
<td>9 9</td>
</tr>
<tr>
<td>Commons-cli</td>
<td>2 3</td>
</tr>
</tbody>
</table>

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