Clustering Solutions of Multiobjective Function Inlining Problem

Kateryna Muts, Heiko Falk

k.muts@tuhh.de, heiko.falk@tuhh.de

Hamburg University of Technology

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Hard real-time systems have several design criteria.

Worst-Case Execution Time (WCET)  code size  energy consumption
Hard real-time systems have several design criteria.

Worst-Case Execution Time (WCET)    code size    energy consumption

Several contradicting objectives → Multiobjective problem
What is a solution of a multiobjective problem?

A set of trade-off solutions

Multiobjective problem
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Multiobjective problem

How to choose the best solution?
How to choose the best solution?

System designer’s preferences

- known
  - before solution process
- unknown
  - before solution process
How to choose the best solution?

System designer’s preferences

- **known**
  - all but one of the objectives are placed into constraints

- **unknown**
  - before solution process

- **known**
  - before solution process

- **unknown**
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How to choose the best solution?

System designer’s preferences

- *known*
  - *before solution process*
    - all but one of the objectives are placed into constraints
- *unknown*
  - *before solution process*
    - all objectives are combined into a single objective
How to choose the best solution?

System designer’s preferences

- all but one of the objectives are placed into constraints
- all objectives are combined into a single objective
- a decision maker conducts in direction of the desired solution

known before solution process

unknown before solution process

known before solution process

- all objectives are combined into a single objective
How to choose the best solution?

System designer’s preferences

- *known* before solution process
  - all but one of the objectives are placed into constraints
- *unknown* before solution process
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↓

one solution
How to choose the best solution?

System designer’s preferences

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before solution process

– all but one of the objectives are placed into constraints

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one solution
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→ one solution

known
before solution process

unknown
before solution process

one solution

0 1 2 3 4 5 6 7 8 9 10 11 12 13

0 1 2 3 4 5 6 7 8 9 10 11 12 13

→ one solution
"The magical number seven, plus or minus two" effect\textsuperscript{1}: Humans can handle only a limited amount of information simultaneously.

\textsuperscript{1}George A. Miller. “The Magical Number Seven, plus or Minus Two: Some Limits on Our Capacity for Processing Information”. In: \textit{Psychological Review} 63 (1956), pp. 81–97.
"The magical number seven, plus or minus two" effect\(^1\): Humans can handle only a limited amount of information simultaneously.

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How to guarantee that the sizes of clusters are less than a predefined size?

Goal: the size of each cluster is less than or equal to 5

Original clustering

Refine large clusters

Merge small clusters

3 clusters  8 clusters  6 clusters
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Original clustering \rightarrow \text{Refine large clusters} \rightarrow \text{Merge small clusters}

Given:

- set $S$ to be clustered
- maximum cluster size $\tau$

$\Rightarrow$ Divide $S$ into $n = \left\lceil \frac{|S|}{\tau} \right\rceil$ clusters by using an existing clustering method\(^2\)

Original clustering $\rightarrow$ Refine large clusters $\rightarrow$ Merge small clusters

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$\Rightarrow$ Divide $S$ into $n = \left\lceil \frac{|S|}{\tau} \right\rceil$ clusters by using an existing clustering method\(^2\)

- K-Means clustering
- Agglomerative clustering
- Spectral clustering

\(^2\)Pedregosa et al., “Scikit-Learn: Machine Learning in Python”.
Original clustering $\rightarrow$ **Refine large clusters** $\rightarrow$ **Merge small clusters**

Given:

- clusters
- maximum cluster size $\tau$
Original clustering → **Refine large clusters** → Merge small clusters

Given:

- clusters
- maximum cluster size $\tau$

- The size of the largest cluster is greater than $\tau$
  - yes: Divide the largest cluster
  - no: Stop
Given:

- Clusters
- maximum cluster size $\tau$
- maximum distance between clusters $dist$
Given:

- Clusters
- maximum cluster size \( \tau \)
- maximum distance between clusters \( dist \)

\[ \Rightarrow \text{Merge two clusters if} \]

- the distance between them is less than \( dist \)
- the size of the merged cluster is less than or equal to \( \tau \)
Function inlining decreases WCET and energy consumption but increases code size.

```c
1   int max (int i, int j)
2   {
3       return i>j?i:j;
4   }
5
6   int main()
7   {
8       ...
9       a = max(c,d);
10      ...
11      b = max(f,g);
12   }
```

```c
1   int main()
2   {
3       ...
4       a = c>d?c:d;
5       ...
6       b = f>g?f:g;
7   }
```
Function inlining decreases WCET and energy consumption but increases code size.

```c
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{
    return i>j?i:j;
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int main()
{
    ...
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    ...
}
```

(WCET, code size, energy consumption) → min
Function inlining decreases WCET and energy consumption but increases code size.

```
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```

(WCET, code size, energy consumption) → min

WCET-Aware Compiler Framework **WCC**
Cluster sizes after each stage of the proposed approach

- **a2time01**
  - Cluster size: 5, 5, 6, 6, 7, 7, 8, 8
  - Stages: Orig., Refine, Merge

- **canrdr01**
  - Cluster size: 5, 6, 6, 6, 8, 8, 9, 9
  - Stages: Orig., Refine, Merge

- **iirflt01**
  - Cluster size: 2, 4, 4, 4, 6, 6, 6, 6
  - Stages: Orig., Refine, Merge

- **pntrch01**
  - Cluster size: 7, 7, 7, 9, 9, 9, 9
  - Stages: Orig., Refine, Merge

- **puwmod01**
  - Cluster size: 5, 10, 15, 15
  - Stages: Orig., Refine, Merge

- **ttsprk01**
  - Cluster size: 12, 14, 14, 14, 18, 21, 20, 20
  - Stages: Orig., Refine, Merge

- **Agglomerative clustering**, **K-Means**, **Spectral clustering**
Clusters for benchmark iirflt01 and spectral clustering

Original clustering

Refinement

Merging

Total:
4 clusters
7 clusters
6 clusters

Total:
4 clusters

96%
98%
100%
102%
104%
106%

96%
98%
100%
102%
104%
106%

96%
98%
100%
102%
104%
106%

WCET
Energy consumption
Code size

WCET
Energy consumption
Code size

WCET
Energy consumption
Code size
Final clusters for benchmark iirflt01

Agglomerative clustering

Total: 6 clusters

K-Means

Total: 6 clusters

Spectral clustering

Total: 6 clusters
Conclusion

– The proposed clustering method guarantees that the sizes of all clusters are less than a predefined limit.

– We demonstrated the approach on multiobjective function inlining with WCET, code size and energy consumption as objectives.

– K-Means, agglomerative and spectral clusterings showed similar results in terms of the number of clusters and their sizes, but agglomerative clustering showed the smallest runtime.
Maximum distance between two clusters

\[ dist = \frac{d_{\text{max}}}{n - 1} \]  

(1)

\( n \) is the number of clusters in the input set \( S \) and \( d_{\text{max}} \) is the maximum distance between two points from the set \( S \):

\[ d_{\text{max}} = \max_{p,q \in S} \| p - q \| \]  

(2)