Clustering Solutions of Multiobjective Function Inlining Problem

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Workshop on Worst-Case Execution Time Analysis (WCET 2023)
July 11, 2023

Hard real-time systems have several design criteria.

Worst-Case Execution Time (WCET)

code size

energy consumption

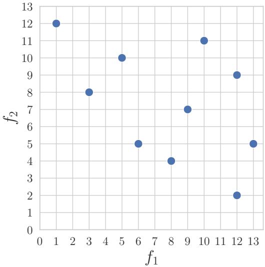
Hard real-time systems have several design criteria.

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

Several contradicting objectives $\longrightarrow$ Multiobjective problem

What is a solution of a multiobjective problem?

A set of trade-off solutions

Multiobjective problem $\longrightarrow$ 

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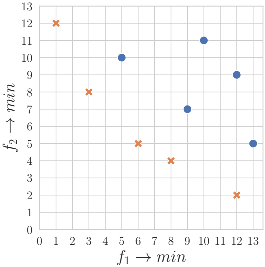
Multiobjective problem $\longrightarrow$

A set of trade-off solutions



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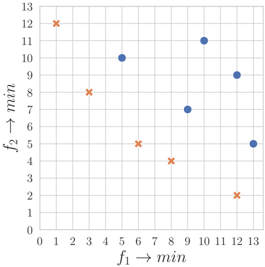
Multiobjective problem ⟶ A set of trade-off solutions



How to choose the best solution?

How to choose the best solution?

System designer's preferences

known

before solution process

unknown

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- all objectives are combined into a single objective

How to choose the best solution?

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known *before solution process*

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- a decision maker conducts in direction of the desired solution

unknown *before solution process*

How to choose the best solution?

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one solution

unknown

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known *before solution process*

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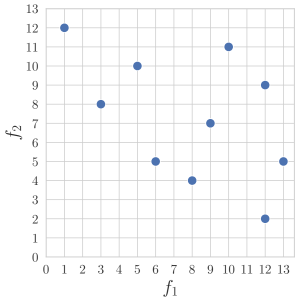
one solution



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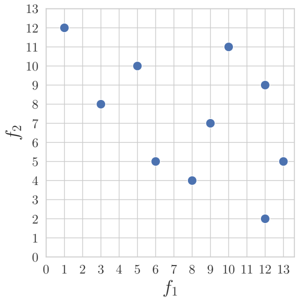
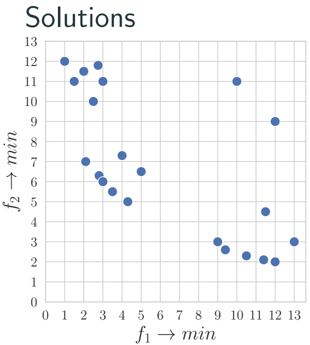
$\downarrow$

one solution



$\longrightarrow$ **one solution**

"The magical number seven, plus or minus two" effect[1]: Humans can handle only a limited amount of information simultaneously.



[1] George A. Miller. "The Magical Number Seven, plus or Minus Two: Some Limits on Our Capacity for Processing Information". In: *Psychological Review* 63 (1956), pp. 81–97.

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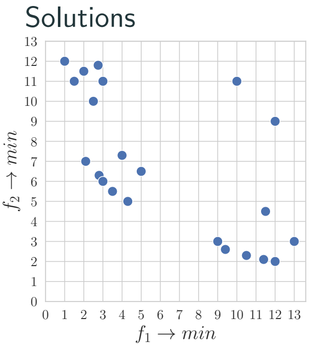

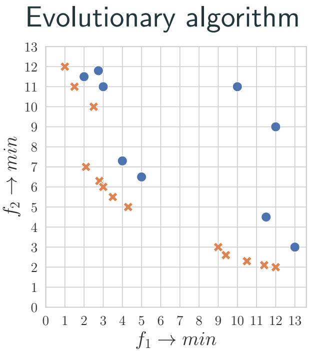

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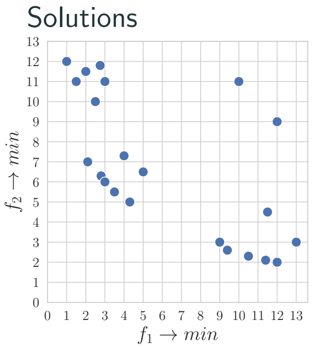

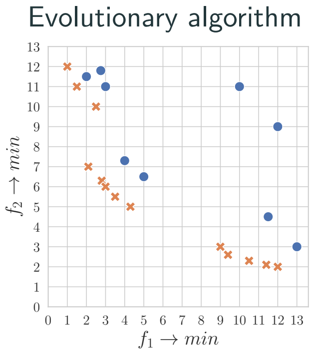

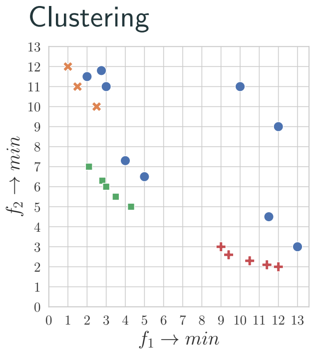

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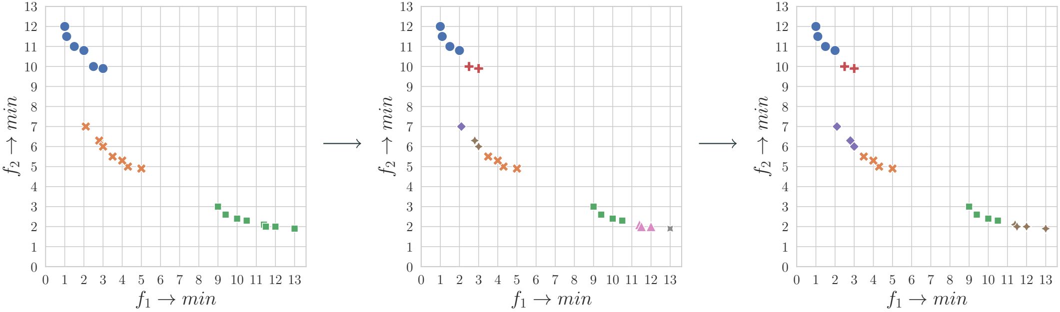
How to guarantee that the sizes of clusters are less than a predefined size?

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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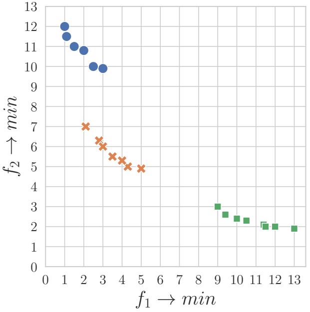

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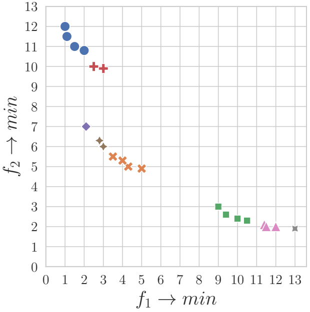
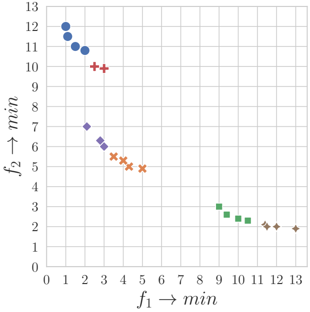


8 clusters

Merge small clusters



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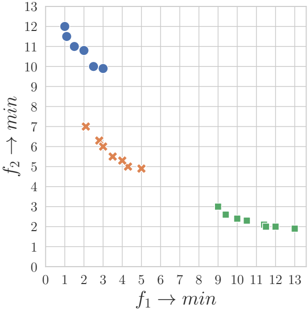

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$\longrightarrow$

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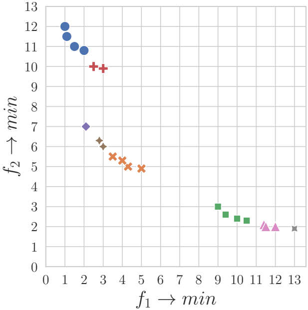

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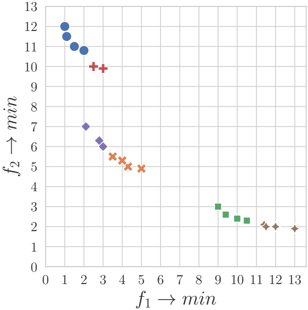

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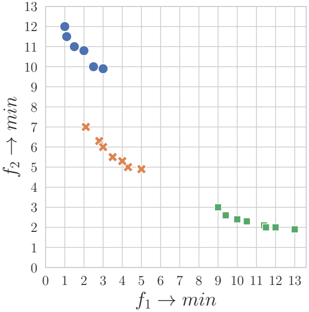

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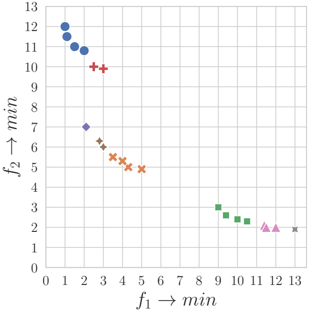

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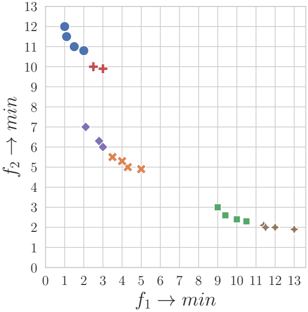

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Original clustering $\longrightarrow$ **Refine large clusters** $\longrightarrow$ **Merge small clusters**

Given:

- set S to be clustered
- maximum cluster size τ

$\Longrightarrow$ Divide S into $n = \left\lceil \frac{|S|}{\tau} \right\rceil$ clusters by using an existing clustering method[2]

[2] Fabian Pedregosa et al. "Scikit-Learn: Machine Learning in Python". In: *Journal of Machine Learning Research* (Jan. 2012). arXiv: `1201.0490v4`.

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- K-Means clustering
- Agglomerative clustering
- Spectral clustering

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$$\textbf{Original clustering} \xrightarrow{\text{Clusters}} \textbf{Refine large clusters} \longrightarrow \textbf{Merge small clusters}$$

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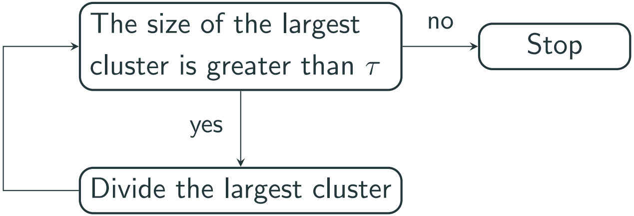

Original clustering $\xrightarrow{\text{Clusters}}$ **Refine large clusters** $\xrightarrow{\text{Clusters}}$ **Merge small clusters**

Given:

- Clusters
- maximum cluster size τ
- maximum distance between clusters *dist*

Original clustering $\xrightarrow{\text{Clusters}}$ **Refine large clusters** $\xrightarrow{\text{Clusters}}$ **Merge small clusters**

Given:

- Clusters
- maximum cluster size τ
- maximum distance between clusters *dist*

$\Longrightarrow$ Merge two clusters if

- the distance between them is less than *dist*
- the size of the merged cluster is less than or equal to τ

Function inlining decreases WCET and energy consumption but increases code size.

```
int max (int i, int j)
{
 return i>j?i:j;
}

int main()
{
 ...
 a = max(c,d);
 ...
 b = max(f,g);
}
```

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int main()
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(WCET, code size, energy consumption) $\longrightarrow$ min

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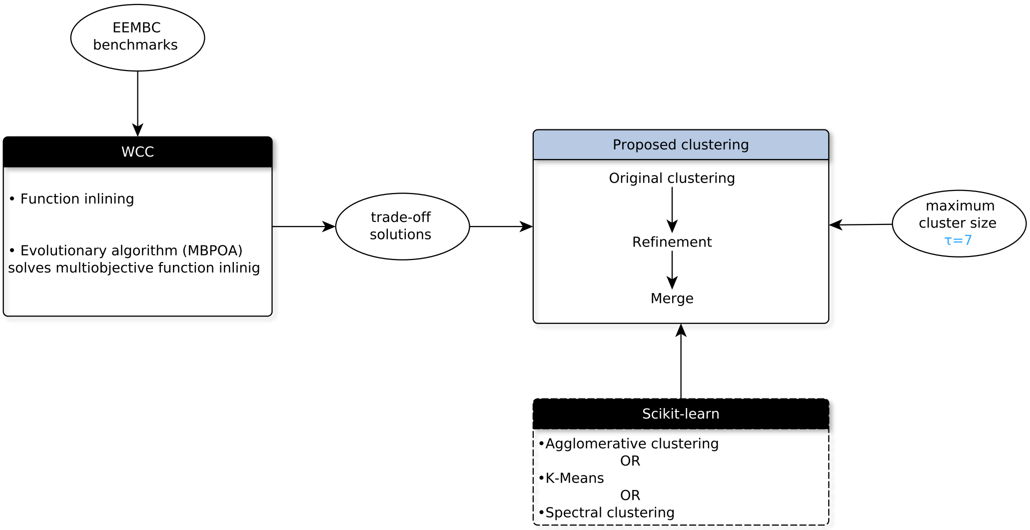
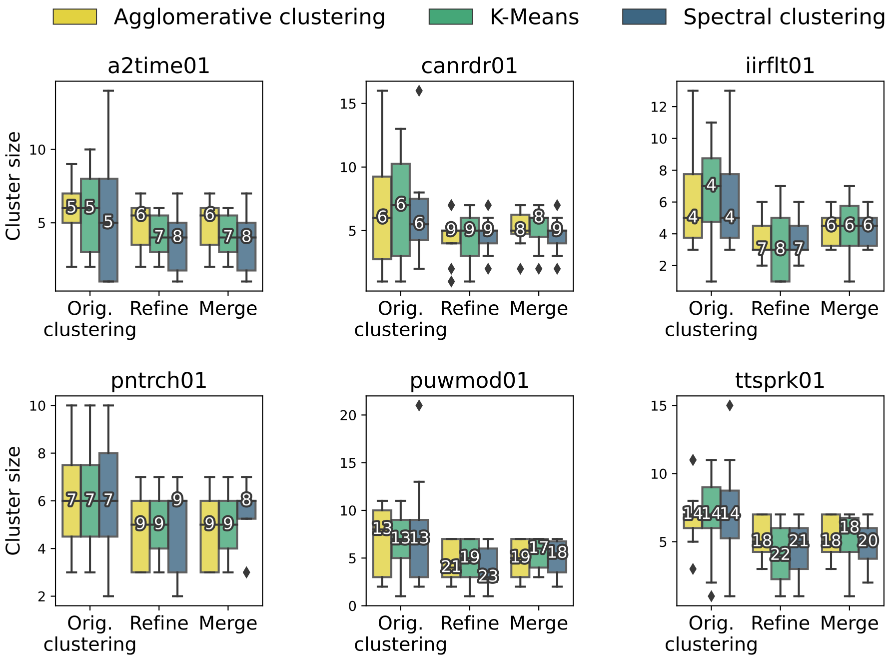
WCET-Aware Compiler Framework **WCC**

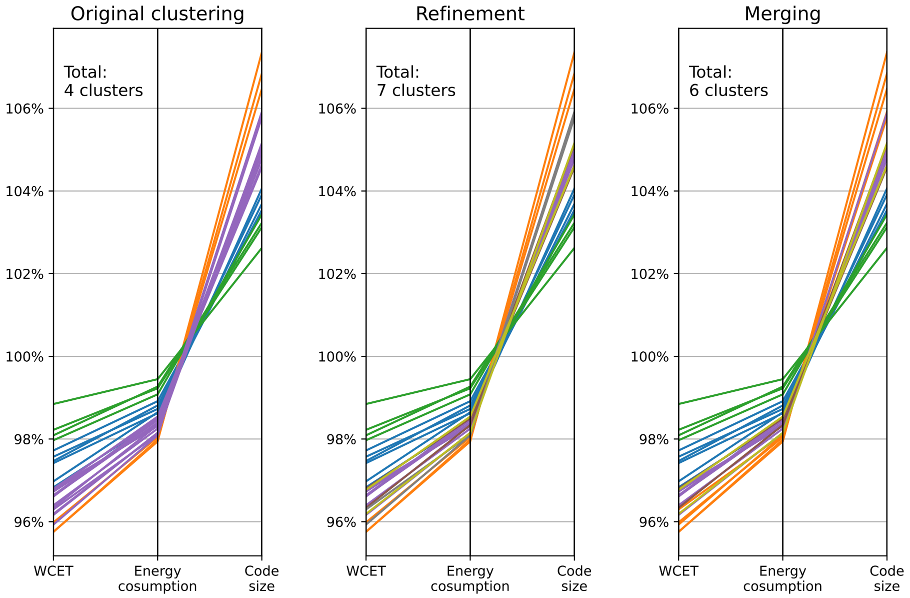
Setup


EEMBC benchmarks
WCC
• Function inlining
• Evolutionary algorithm (MBPOA) solves multiobjective function inlinig
trade-off solutions
Proposed clustering
Original clustering
Refinement
Merge
maximum cluster size
τ=7
Scikit-learn
•Agglomerative clustering
OR
•K-Means
OR
•Spectral clustering

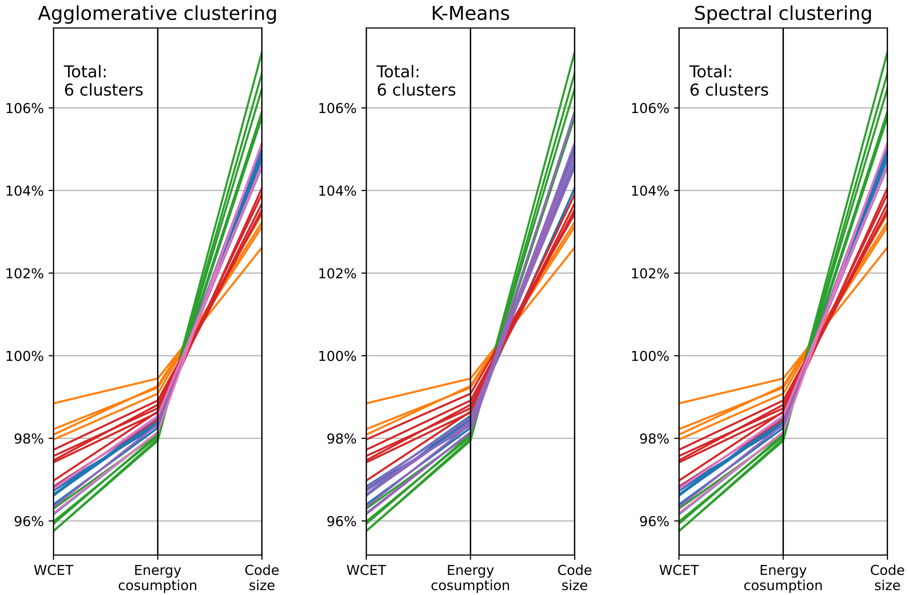
Cluster sizes after each stage of the proposed approach



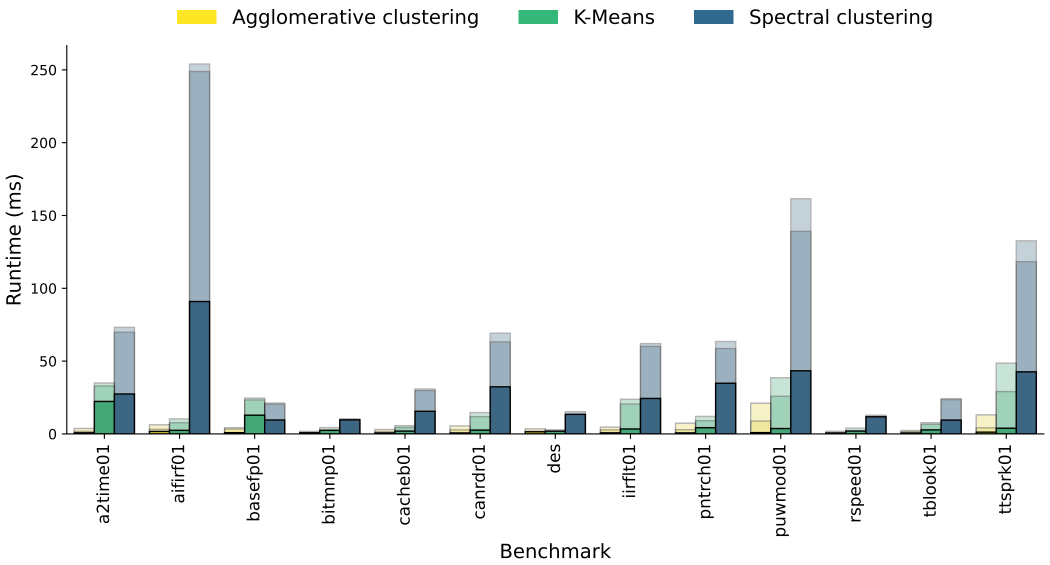
Clusters for benchmark iirflt01 and spectral clustering



Final clusters for benchmark iirflt01



Runtime


Agglomerative clustering
K-Means
Spectral clustering
Runtime (ms)
0
50
100
150
200
250
a2time01
aifirf01
basefp01
bitmnp01
cacheb01
canrdr01
des
iirflt01
pntrch01
puwmod01
rspeed01
tblook01
ttsprk01
Benchmark

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

$$dist = \frac{d_{max}}{n-1} \tag{1}$$

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

$$d_{max} = \max_{p,q \in S} ||p - q|| \tag{2}$$