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Tree Encoding Technique for Block Diagram

Encoding Technique of Genetic Algorithms for Block Definition Diagram using OMG SysML™ Notations

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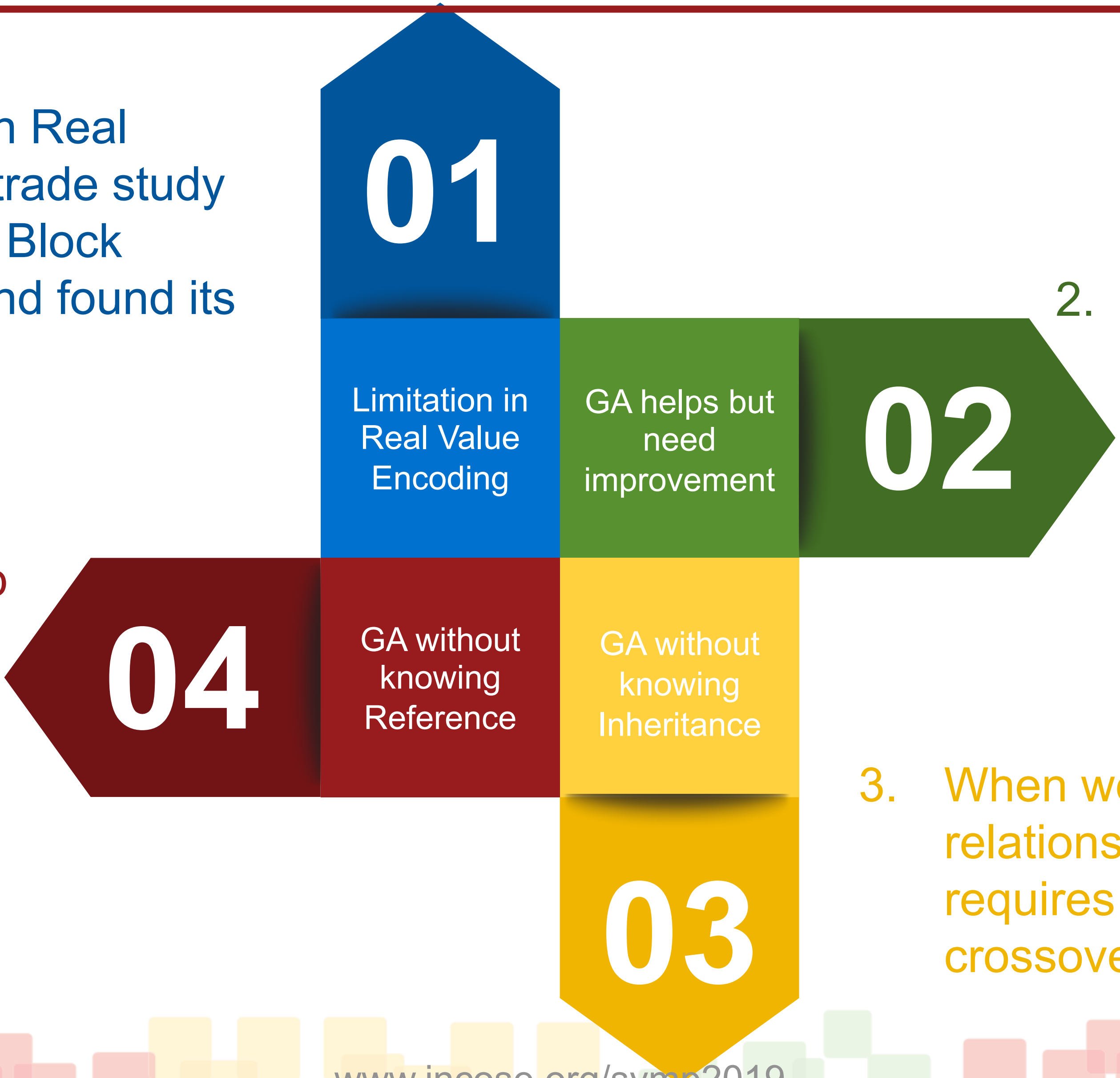
Problems with Real Value Encoding

1. We applied a GA with Real Value encoding in a trade study based on the SysML Block Definition Diagram and found its limitation.

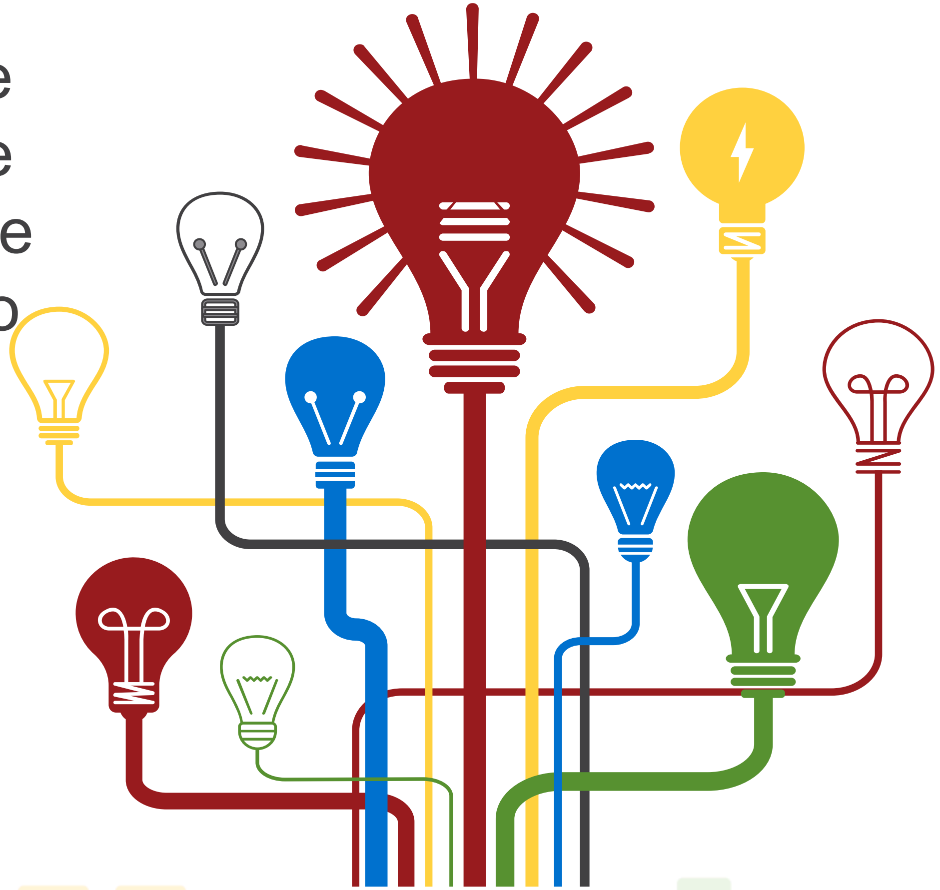


2. The limitation of Real Value Encoding technique is that it can only recognize the value, not the relationships among the subsystems.
3. When we have an inheritance relationship between blocks, it requires us to perform manual crossovers and mutations.
4. When we have a reference relationship between blocks we need to exclude the reference block manually from the chromosome collection.

Objective

To overcome the shortcoming of GA with Real Value Encoding that causes it to fail to recognize the BDD relationships of its subsystems.

This study proposes a tree encoding technique for the OMG SysML™ BDD to use with a Genetic Algorithm to automate components selection in design synthesis.



We focus on solving encoding problems on BDD so that manual encoding processes in the GA trade study analysis can be eliminated.

Real Value vs. Tree Encoding

Real Value Encoding

- It is a technique where each chromosome is a simple string of values, which could be anything such as real numbers, characters, or complicated object (CSE UNSW, 2018).

Tree Encoding

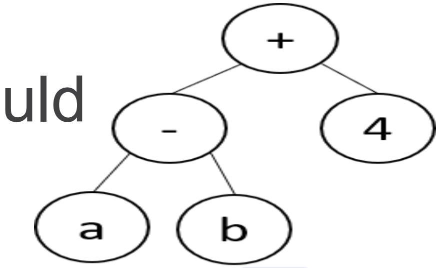
- It is a technique that presents each chromosome as a tree of some object connected in special sequence like function on the programming language (CSE UNSW, 2018)
- The tree structure also represents the object's hierarchy, which is a good match for the whole-part relationship.

Given a - b + 4

What real-value encoding would look like:

a	b	4

What tree encoding would look like:



Methodology

Simplified Block Definition Diagram → **Formal Semantics** → **Tree Encoding**

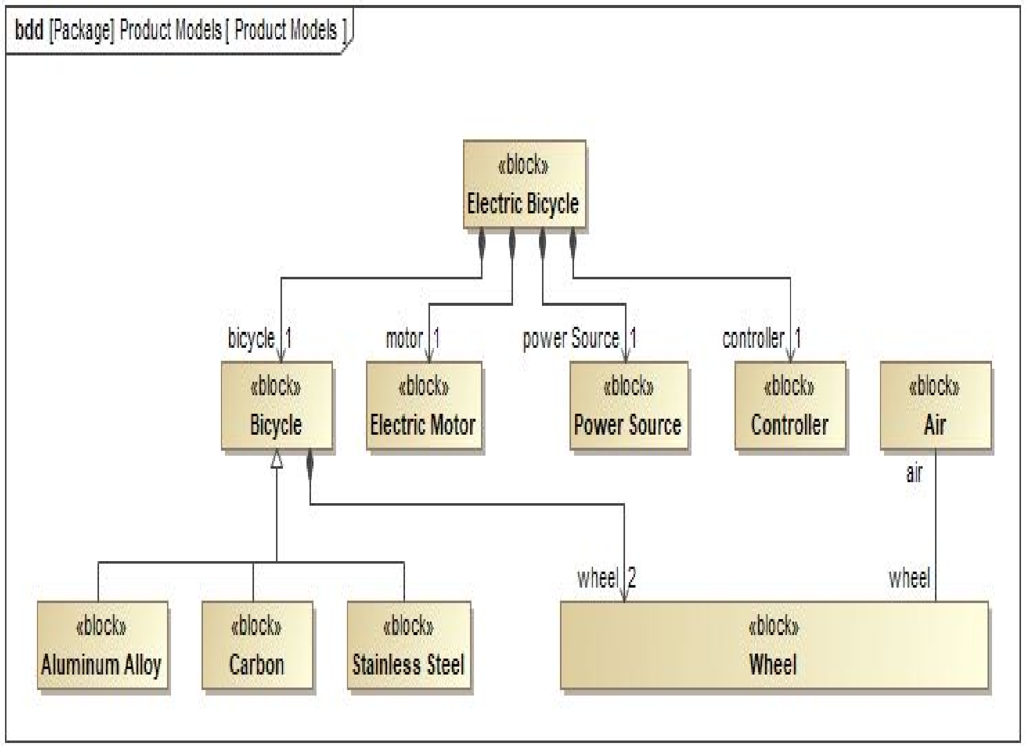
Simplified Block Definition Diagram: Convert BDD to Simplified BDD

Formal Semantics: Translate Simplified BDD to Formal Semantics

Tree Encoding: Encode Formal Semantics into Tree Encoding

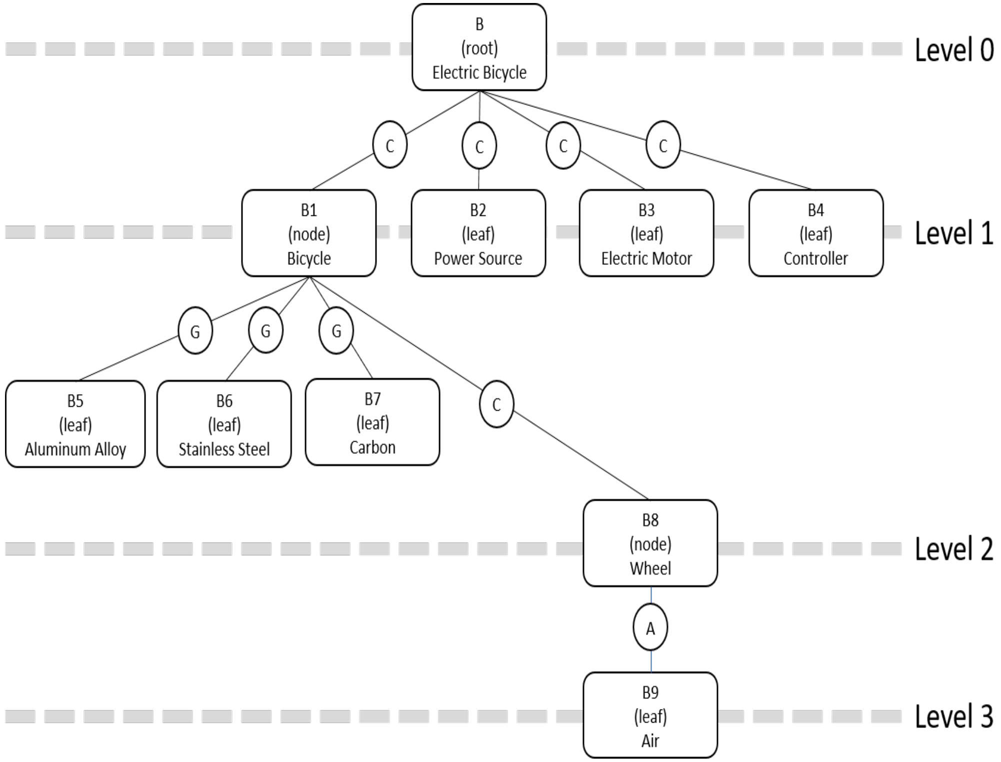
Simplified BDD into RNL Tree

An electric bicycle is used as a case study to transform the BDD with tree encoding into formal semantics.



Block Definition Diagram

Transform



Simplified BDD in RNL Tree

Translate Simplified BDD to Formal Semantics

Given B contains:

B ∋ Comp(B,B1) ∪ Comp(B,B2) ∪ Comp(B,B3) ∪ Comp(B,B4)

A breakdown of B is as follows:

- **B1 ∋ Herit(B1,B5) ∪ Herit(B1,B6) ∪ Herit(B1,B7) ∪ Comp(B1,B8)**
- **B2 ∋ None**
- **B3 ∋ None**
- **B4 ∋ None**
- **B5 ∋ None**
- **B6 ∋ None**
- **B7 ∋ None**
- **B8 ∋ Ass(B8,B9)**
- **B9 ∋ None**

Therefore, after B1 and B8 have been replaced with the breakdown of formal semantics, a complete form of B will be:

B ∋ Comp(B,Herit(B1,B5) ∪ Herit(B1,B6) ∪ Herit(B1,B7) ∪ Comp(B1,Ass(B8,B9))) ∪ Comp(B,B2) ∪ Comp(B,B3) ∪ Comp(B,B4)

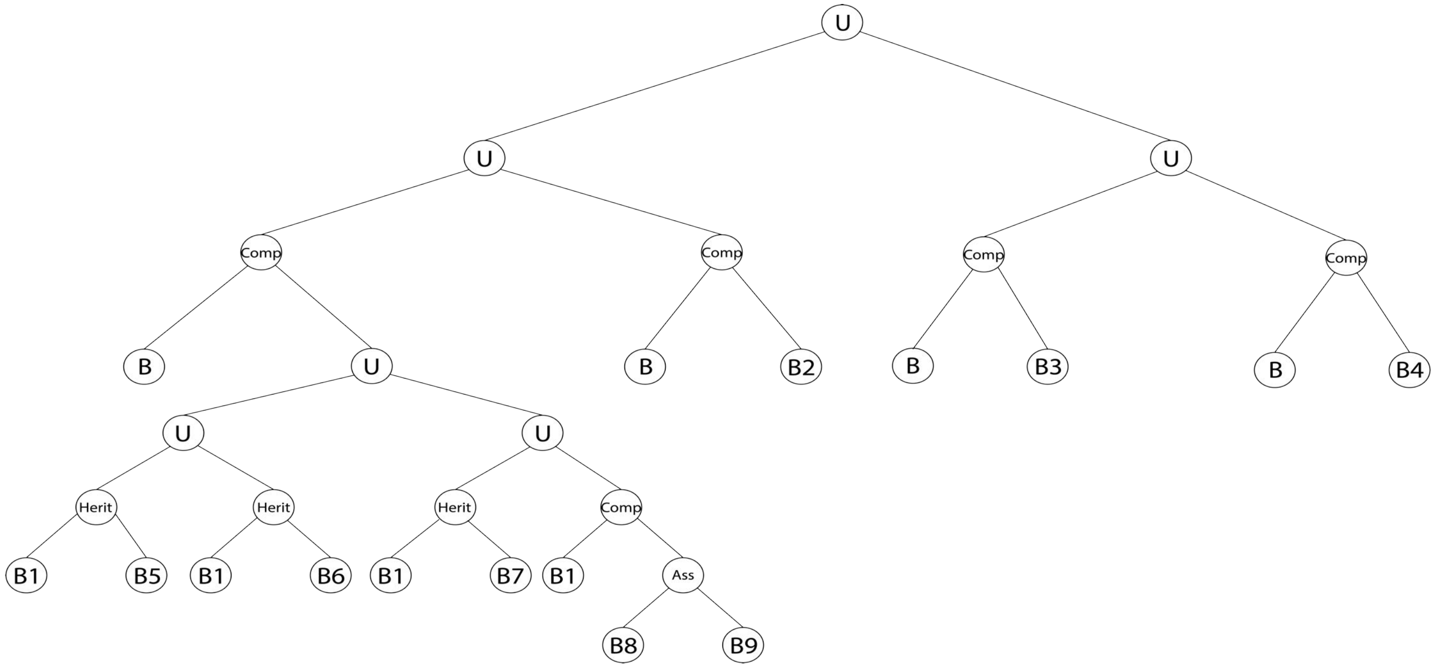
An electric bicycle (B) has parts (COMPOSITION OF) a bicycle (B1), a power source (B2), an electric motor (B3), and a controller (B4).

Aluminum alloy (B5), stainless steel (B6), and carbon (B7) inherit from the bicycle (B1).

The bicycle (B1) has part (composition of) wheels (B8) where the wheels (B8) are related (ASSOCIATION) to air (B9).

Encode Formal Semantics into Tree Encoding

- The tree encoding of the electric bicycle shows the chromosomes set that consists of 9 genes.
- No manual custom crossovers and mutations are required for Bicycle (B1) and GA recognizes the different types of the bicycle from the SysML inheritance relationships for aluminum alloy (B5), stainless steel (B6), and carbon (B7).



9 Genes recognized from the electric bicycle BDD:

B1 = Bicycle
B2 = Power Source
B3 = Electric Motor
B4 = Controller
B5 = Aluminum Alloy
B6 = Stainless Steel
B7 = Carbon
B8 = Wheel
B9 = Air

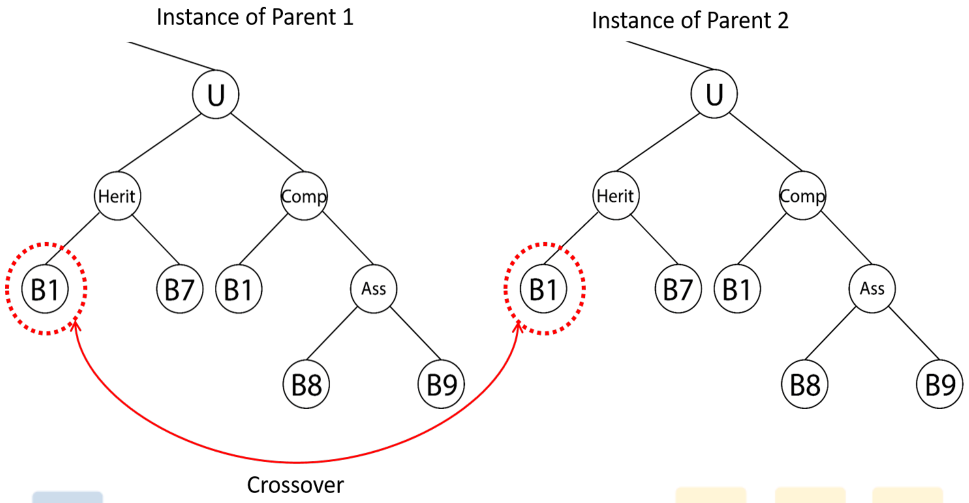
Crossover and Mutation with Tree Encoding

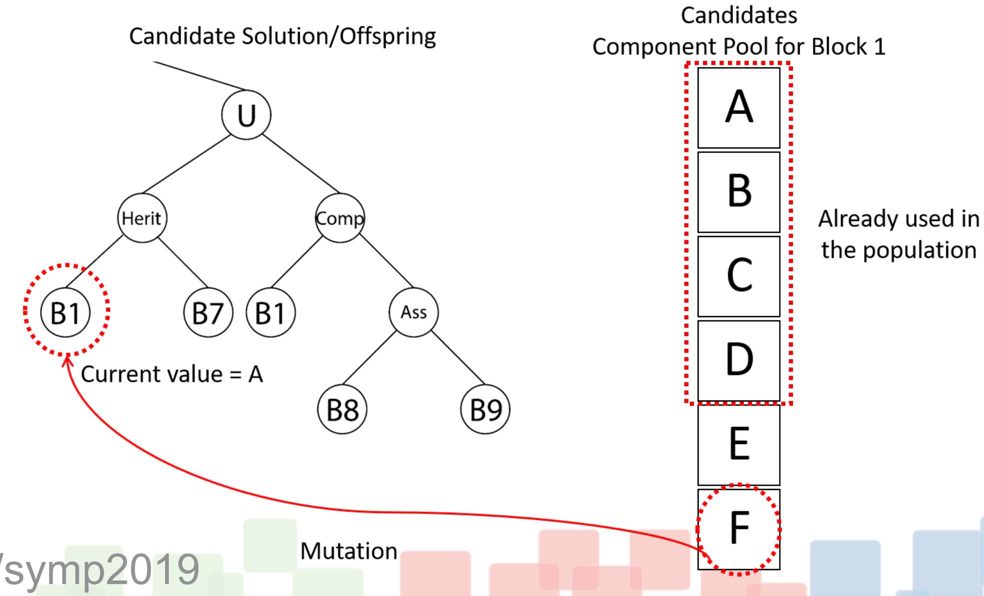
Example of Crossover with Tree Encoding

- The crossover process happens to Bicycle (B1) gene from the instances of both parents.
- In a real application, the crossover can be performed on multiple points (genes) of the parents.
- Moreover, the tree encoding allows the crossover on BDD relationships.

Example of Mutation with Tree Encoding

- The mutation process happens to Bicycle (B1) gene from the candidate solutions/offspring.
- Before the mutation, the current value of Bicycle (B1) is component A.
- Then, the new value is randomly taken from an unused component pool that is suitable for Bicycle (B1).
- The new value (component F) is a mutated component because it is different from the other components among all candidate solutions/offspring in the same population.





Conclusion

1. Real-value encoding in GA is a less appropriate technique to encode the elements of OMG SysML™ because the relationships in a system model cannot be ignored in performing automated reasoning.

2. Tree encoding is an easy method to represent the semantics in BDD including the blocks and their relationships within a tree structure.

3. The tree structure is capable of supporting the reasoning based on the OMG SysML™ block's relationships.

Future Work

01	Reasoning based on multiplicity & role	Make use of reasoning to include multiplicity and role of BDD, and thoroughly investigate the value properties (such as value type) of each block.
02	Complete reasoning for SysML	Build a complete reasoning ability in OMG SysML™ and apply the encoding technique to all diagrams.
03	Quantitative measurement on parameters	Quantitative measurement can be performed to compare the encoding techniques with parameters, such as performance speed and memory consumption.
04	Formal semantics tree	The formal semantics tree can be easily separated by using the Polish/prefix notation.

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