面向SystemVerilog Constraints的通用约束求解器

集成电路 EDA 设计精英挑战赛（合见工软）赛题讲解

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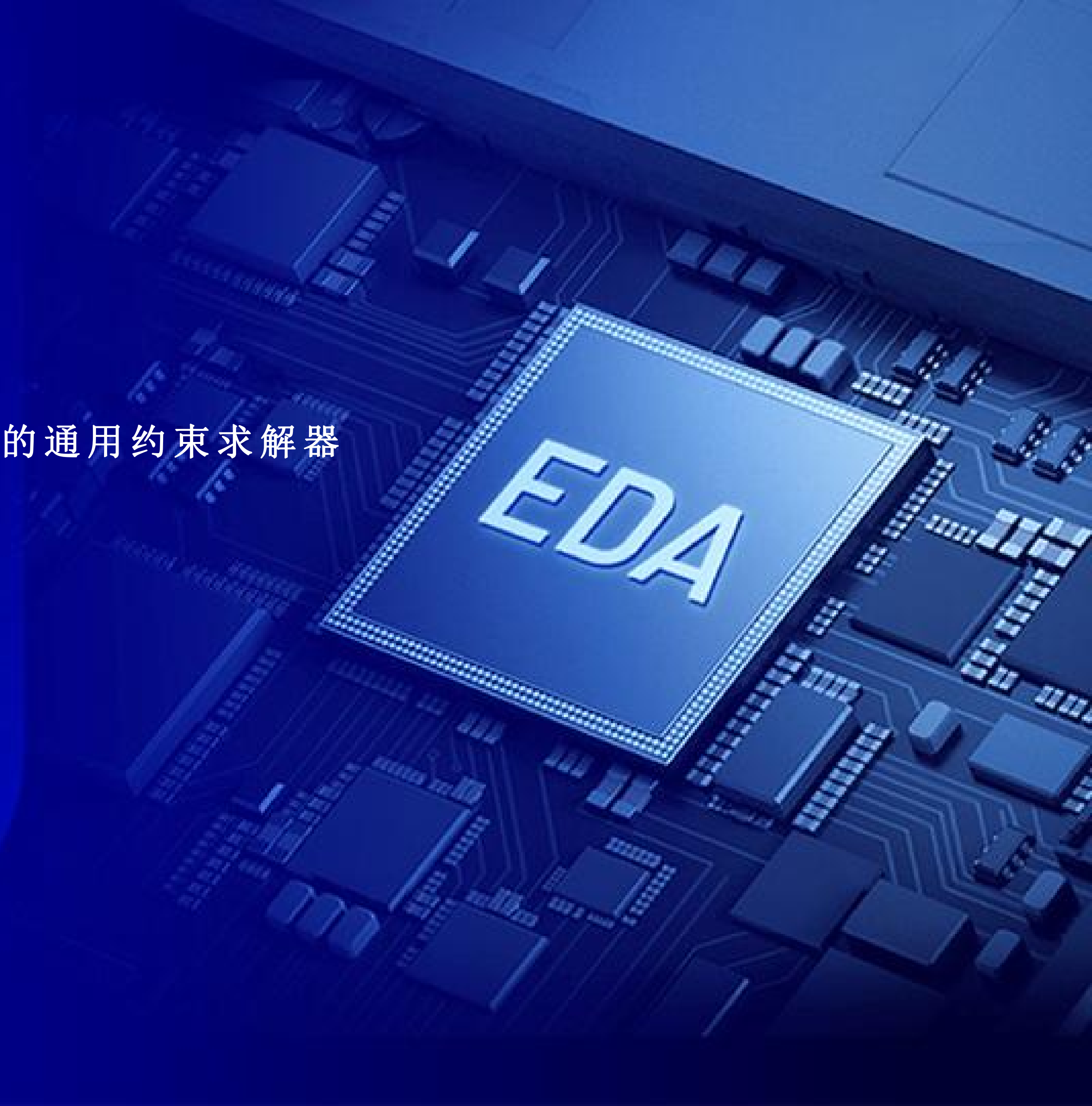

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- Formal verification v.s. simulation based verification
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背景介绍 – 求解器简介

- Solver简介
- 类型：SAT, SMT, CSP and BDD-based
- 特性：正确性，随机性和可重现，概率分布，性能要求

赛题详解 – 约束问题定义

约束问题，由变量、常量和表达式组成，其中

- 变量是无符号(unsigned)的、具有固定位宽(bit-width)的位向量(bit-vector)
  - 比如bit[7:0] x;定义了一个unsigned的8bit位宽的变量。
- 常量是有符号或无符号、具有固定位宽的整型数
- 表达式由操作数和运算符构成，操作数可以常量或变量，运算符有以下6类：
  - 逻辑运算： &&, ||, !
  - 位运算： &, |, ^, ~ …
  - 算术运算： +, -, *, /, %
  - 关系运算: >, <, >=, <=, ==, !=

赛题详解 – 约束问题示例

```
bit[1:0] x,y,z;
x > y;
y > z;
```

随机解1：

x = 2’b11

y = 2’b10

z = 2’b01

随机解2：

x = 2’b10

y = 2’b01

z = 2’b00

…

赛题详解 – BDD & CUDD

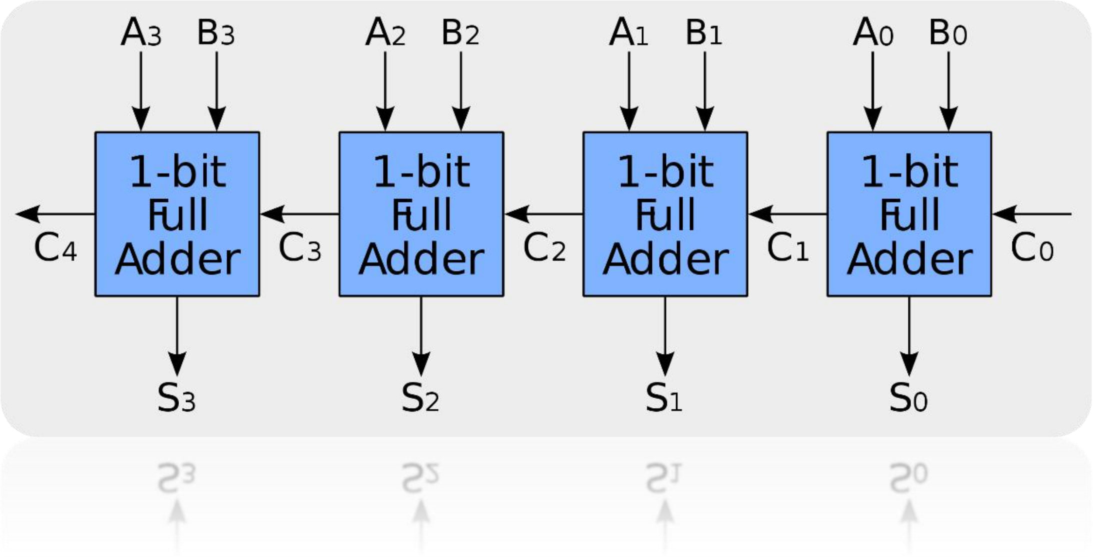
BDD[9,10]是一种可以用来表达布尔函数的数据结构。在形式化验证、电路验证中，许多任务都涉及大型命题逻辑公式的运算，BDD在这些领域中有着广泛的应用。在约束问题求解中，因为约束本身就是一系列逻辑、位运算和算术运算组成的表达式，所以也可以通过基于BDD的运算来实现。

CUDD是一个用于计算和处理BDD/ADD/ZDD的开源库。使用CUDD提供的API可以比较方便地从表达式计算得到BDD

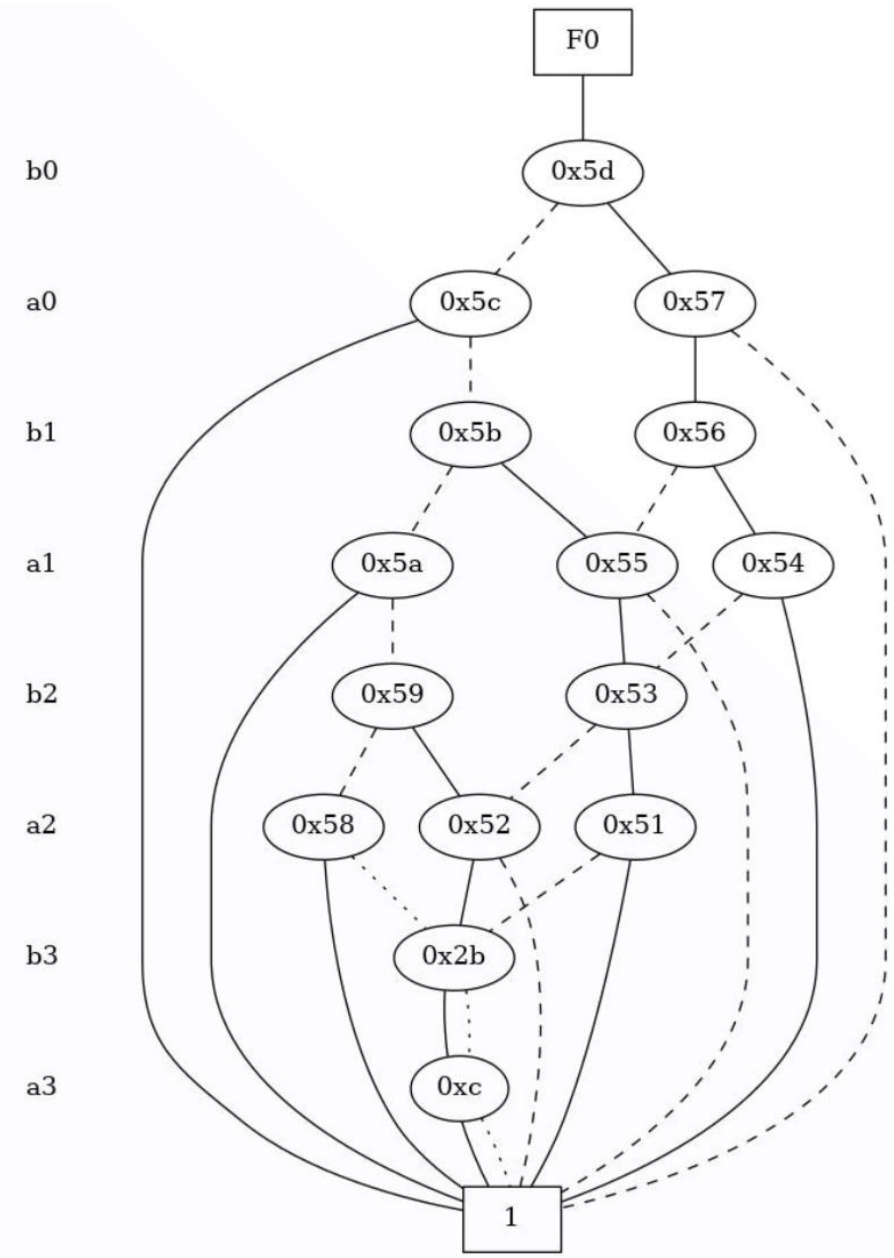
赛题详解 – BDD & CUDD

bit[3:0] A,B;

A + B > 4’b0000



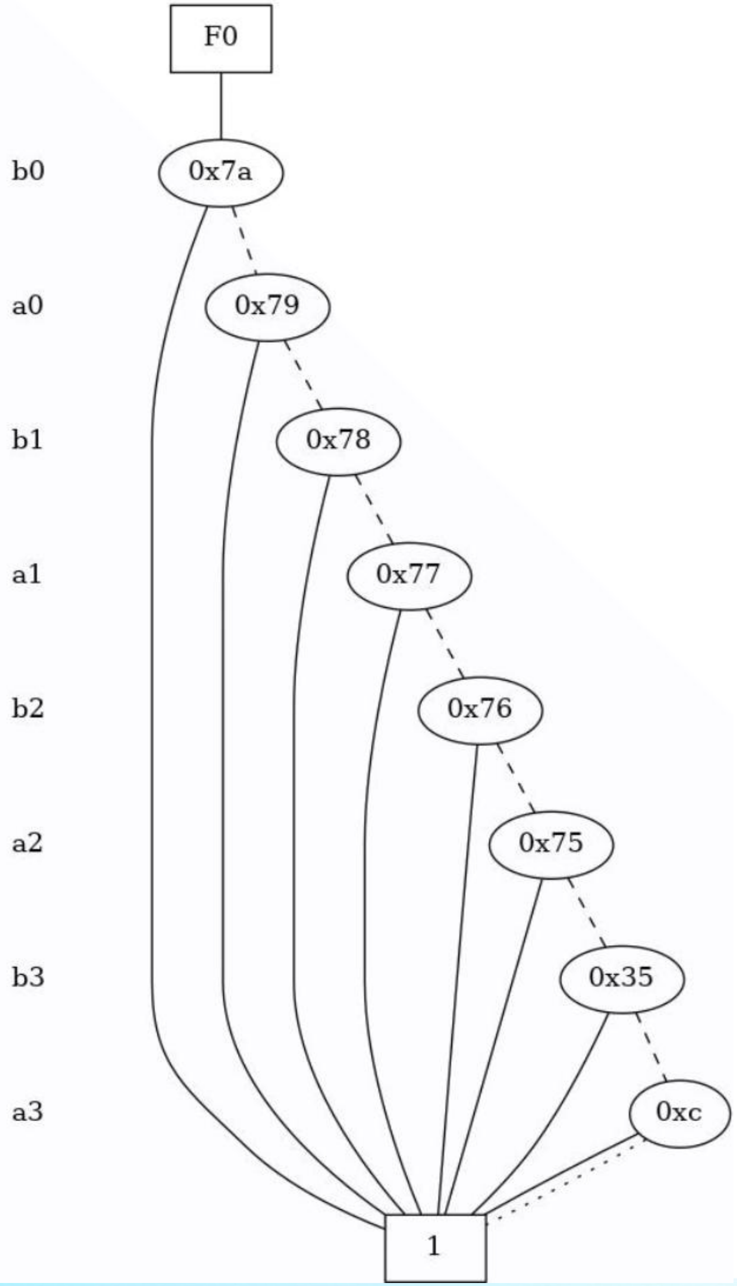
```
#include "cuddObj.hh"
BDD a0, a1, a2, a3, b0, b1, b2, b3; // bddVar
BDD s0, s1, s2, s3;
BDD result;

a0 = bddVar();
...

s0 = a0 ^ b0;
c0 = (a0 & b0);
s1 = a1 ^ b1 ^ c0;
c1 = (a1 & b1) | (c0 & (a1 | b1))
s2 = a2 ^ b2 ^ c1;
c2 = (a2 & b2) | (c1 & (a2 | b2))
s3 = a3 ^ b3 ^ c2;
c3 = (a3 & b3) | (c2 & (a3 | b3))

result = s0.Xor(s1.Xor(s2.Xor(s3)))
```



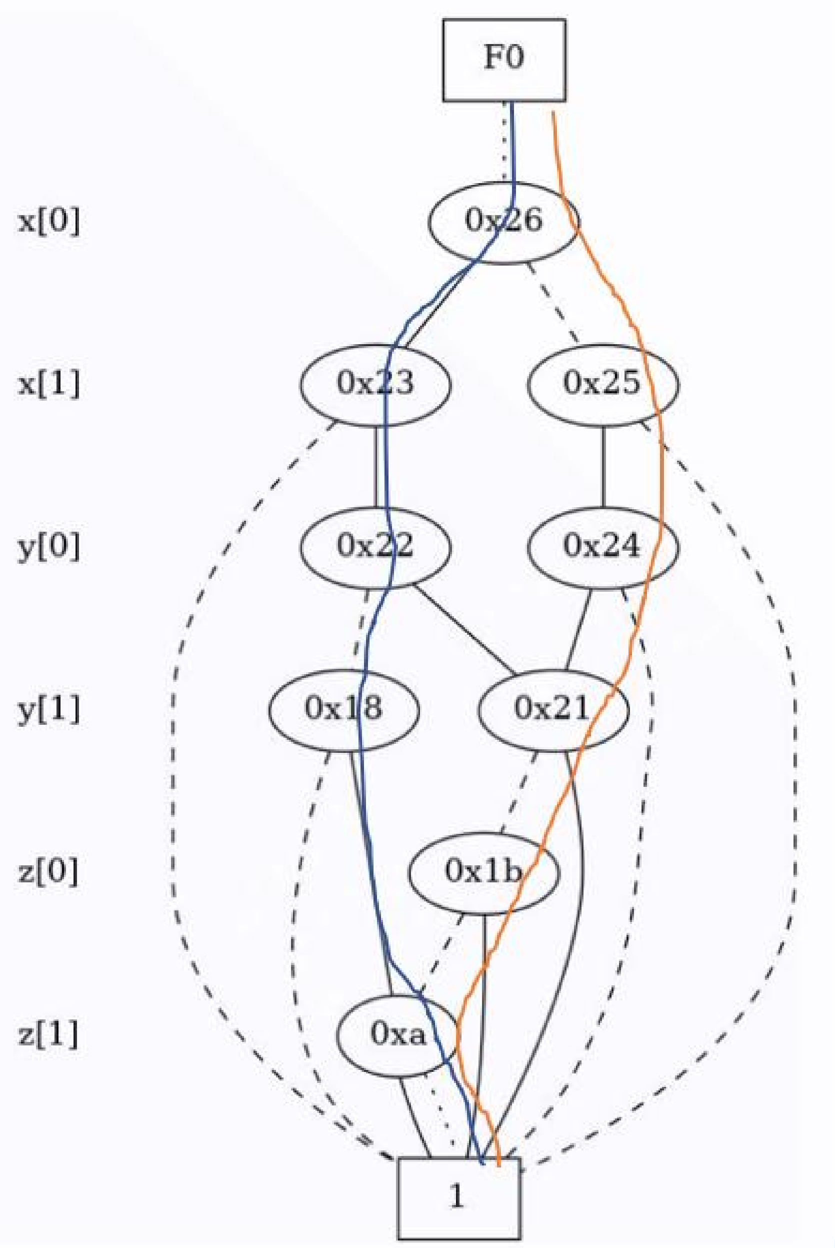
bit[3:0] A,B;

A + B > 0

32’(A) + 32’(B) > unsigned’(0)



```
bit[1:0] x,y,z;

x > y;

y > z;
```



The CUDD package, BDD, ADD Tutorial and examples | David Kebo

Henrik Reif Andersen. An Introduction to Binary Decision Diagrams. Fall, 1999

bdd.pdf (utexas.edu)

```
"variable_list":
[
	{			// variable
				"id": <number>,
				"name": <string>,
				"signed": <true_of_false>,
				"bit_width": <number>
	},
	...
]

"constraint_list":
[
	{			// expression
				"op": <string> // operator type
				"id": <number> // variable id if op is VAR
				"value": <number> // hexical number is op is CONST
				"lhs_expression": // if op is another type
				{			// lhs expression
							// same as above expression format
				}
				"rhs_expression": // if op is another type and rhs exists
				{			// rhs expression
							// same as above expression format
				}
				"if_expression": // if op is MUX(If-Then-Else), if: if_expression,
then: lhs_expression, else: rhs_expression
				{			// pred expression
							// same as above expression format
				}
	}
]
```

```
"assignment_list":
[
	[			// assignment 1
				{"value": <number>} // hexical number, sorted in asending
order of variable ids
				{"value": <number>}
				...
	]
	[			// assignment 2
				...
	]
	...
]
```

Constraint Problem:

```
bit [31 : 0] a;
bit [31 : 0] b;
bit [31 : 0] c;
bit [31 : 0] abj_a;
bit [31 : 0] abj_b;
bit [31 : 0] abj_c;
constraint cb {
(abj_a < 32'h0000064);
(abj_b < 32'h00000064);
(abj_c < 32'h0000064);
(abj_a == a);
(abj_b == b);
(abj_c == c);
((a * b) * c) == 32'h0000000533);
}
```

Constraint Problem in Json:


```
{
"variable_list": [
    { "id": 0, "name": "a", "signed": false, "bit_width": 32 },
    { "id": 1, "name": "b", "signed": false, "bit_width": 32 },
    { "id": 2, "name": "c", "signed": false, "bit_width": 32 },
    { "id": 3, "name": "abj_a", "signed": false, "bit_width": 32 },
    { "id": 4, "name": "abj_b", "signed": false, "bit width": 32 },
    { "id": 5, "name": "abj_c", "signed": false, "bit_width": 32 }
],
"constraint list": [
    {
            "op": "LT",
            "lhs_expression": { "op": "VAR", "id": 3 },
            "rhs_expression": { "op": "CONST", "value": "0000000001234556789012345678901234567890" }
    },
    ...
    {
            "op": "EQ",
            "lhs_expression": {
                    "op": "MUL",
                    "lhs_expression": {
                            "op": "MUL'
                            "lhs_expression": { "op": "VAR", "id": 0 },
                            "rhs_expression": { "op": "VAR", "id": 1 }
                    },
                    "rhs_expression": { "op": "VAR", "id": 2 }
            },
            "rhs_expression": { "op": "CONST", "value": "000001533" }
    }
]
}
```

results in Json:


```
{
"assignment_list":
[
	[
		{"value": "0"},
		{"value": "1"},
		{"value": "2"},
		{"value": "3"},
		{"value": "4"},
		{"value": "5"}
	],
	[
		{"value": "5"},
		{"value": "4"},
		{"value": "3"},
		{"value": "2"},
		{"value": "1"},
		{"value": "0"}
	],
	[
		{"value": "5"},
		{"value": "4"},
		{"value": "3"},
		{"value": "2"},
		{"value": "1"},
		{"value": "0"}
	]
}
```

赛题详解 – 任务分解

1.读取问题文件，存储到内部数据结构

2. 精度转换

3.遍历表达式，使用CUDD API构造BDD

4.基于BDD，挑选合法路径

5.输出随机解到文件

评分标准

本赛题将提供一定数量的测试用例，其中包含了从简单到复杂不同难度的问题。所有的测试用例赛前不对参赛者公开。每个测试用例分配相同的分值，最后根据总分评判参赛者排名。赛前会提供若干测试用例和输出结果的样本，供参赛者练习参考使用。

评分标准包括3个部分：

1) 输出结果必须保证正确性；
2) 性能通过程序的执行时间来评判；
3) 输出结果需要符合均匀联合随机分布；

根据以上标准每个测试用例的评分步骤如下，具体细则另行说明：

1) 检查结果正确性，任意一组值错误，本用例得分为0；
2) 检查结果分布，如随机值分布偏差过大，本用例得分为0；
3) 通过正确性和分布检查后，根据性能排名评分：假设参赛人数为N，名次为M，得分根据以下公式计算

Score=10*（N-M+1）/N

第一名得10分，第二名得(N-1)*10/N……

最后将每个测试用例的分数相加得到总分。

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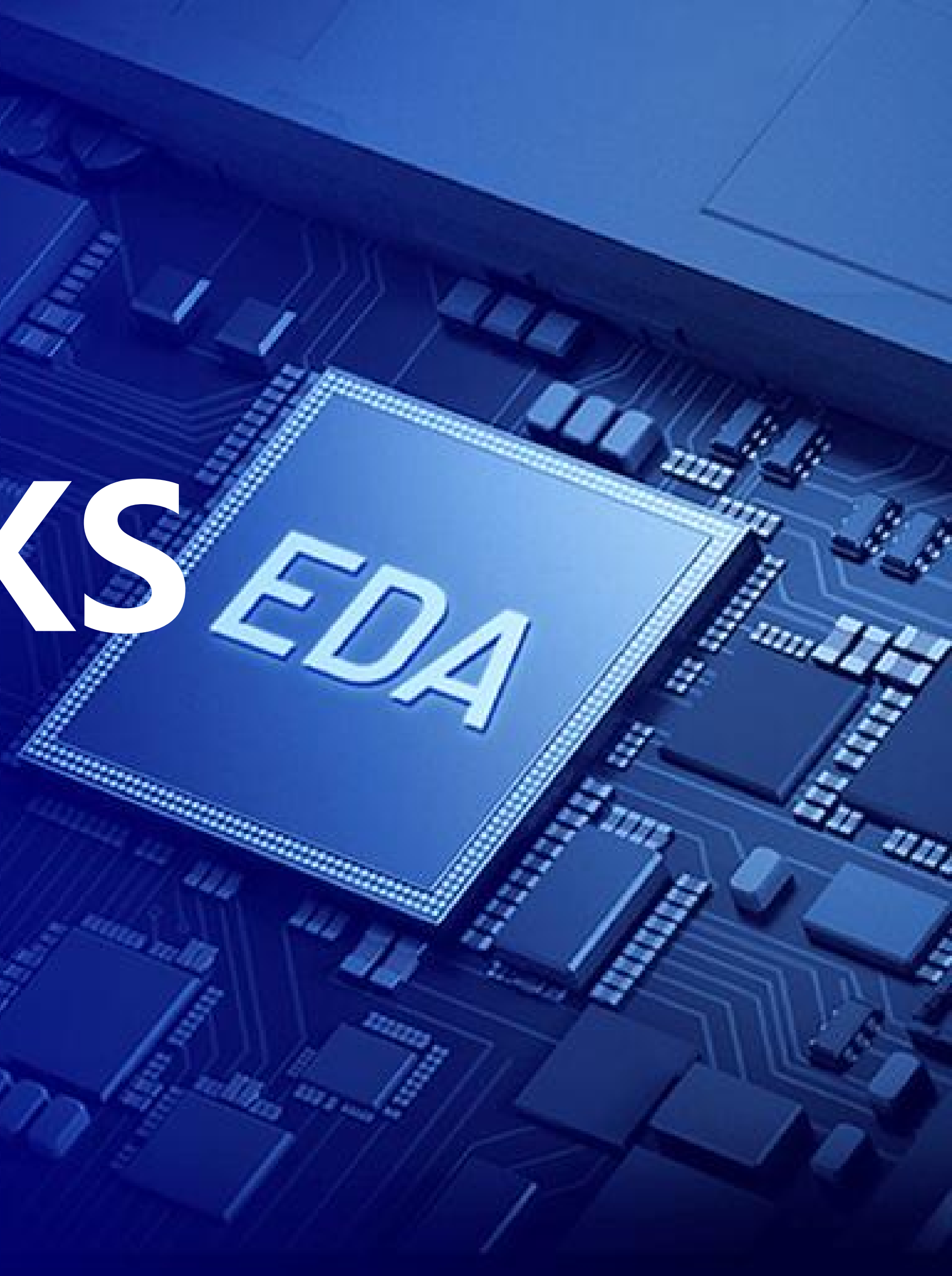
THANKS



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