

Combinatorial Methods for Modelling Complex Systems

The Automotive Case

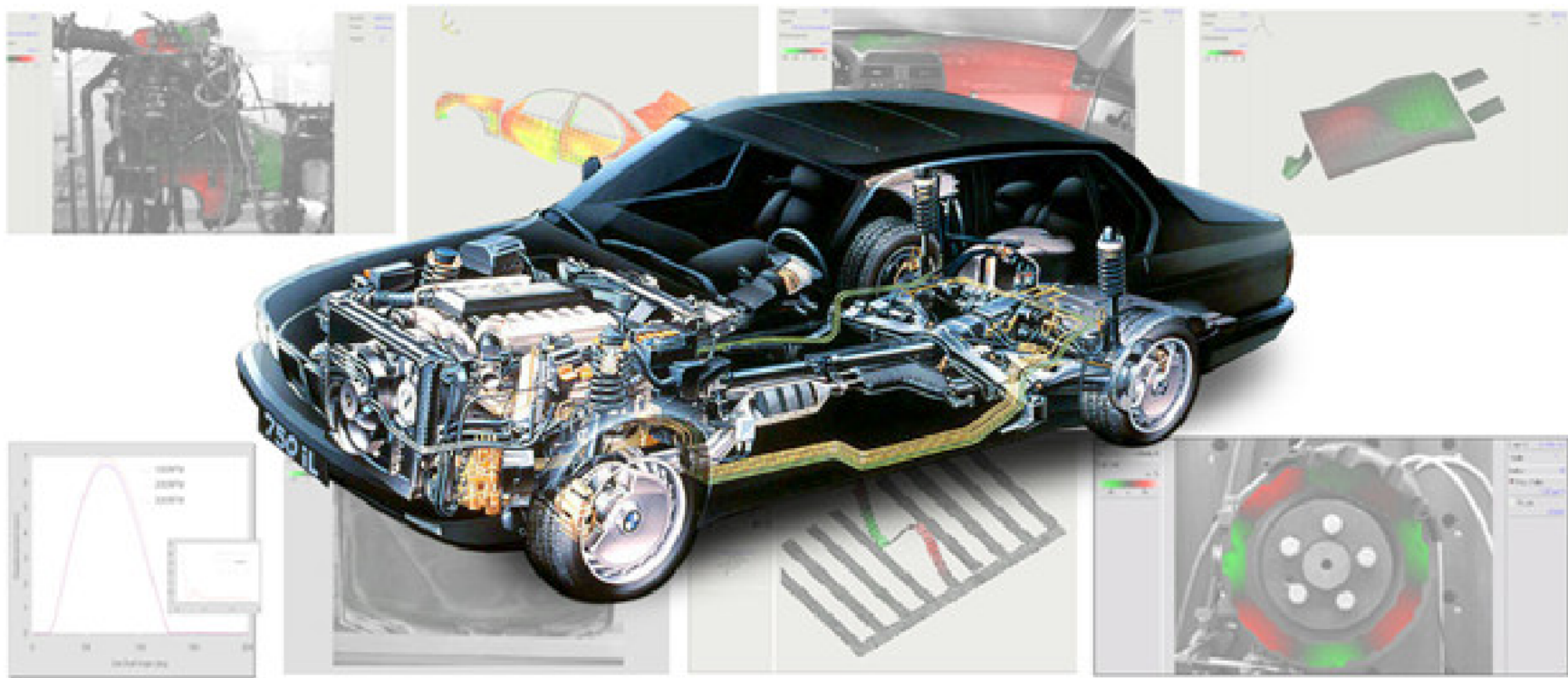
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IMPACT

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Combinatorial Testing in a Nutshell

System with 3 Boolean Input Parameters a, b, c

- Could be function, application, configuration file, etc.
- Exhaustive test set: $2^3 = 8$ tests
- 2-way combinatorial test set: 4 tests

a	b	c	(a, b)	(b, c)	(a, c)
0	0	0	(0, 0)	(0, 0)	(0, 0)
0	1	1	(0, 1)	(1, 1)	(0, 1)
1	0	1	(1, 0)	(0, 1)	(1, 1)
1	1	0	(1, 1)	(1, 0)	(1, 0)

Table: 2-way test set (left) covering all pairs of parameters (right)

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Table: 2-way test set (left) covering all pairs of parameters (right)

Advantages grow for larger systems (e.g. 10 boolean parameters)

- Exhaustive: $2^{10} = 1024$ tests $\rightarrow$ 2-way test set: 6 tests

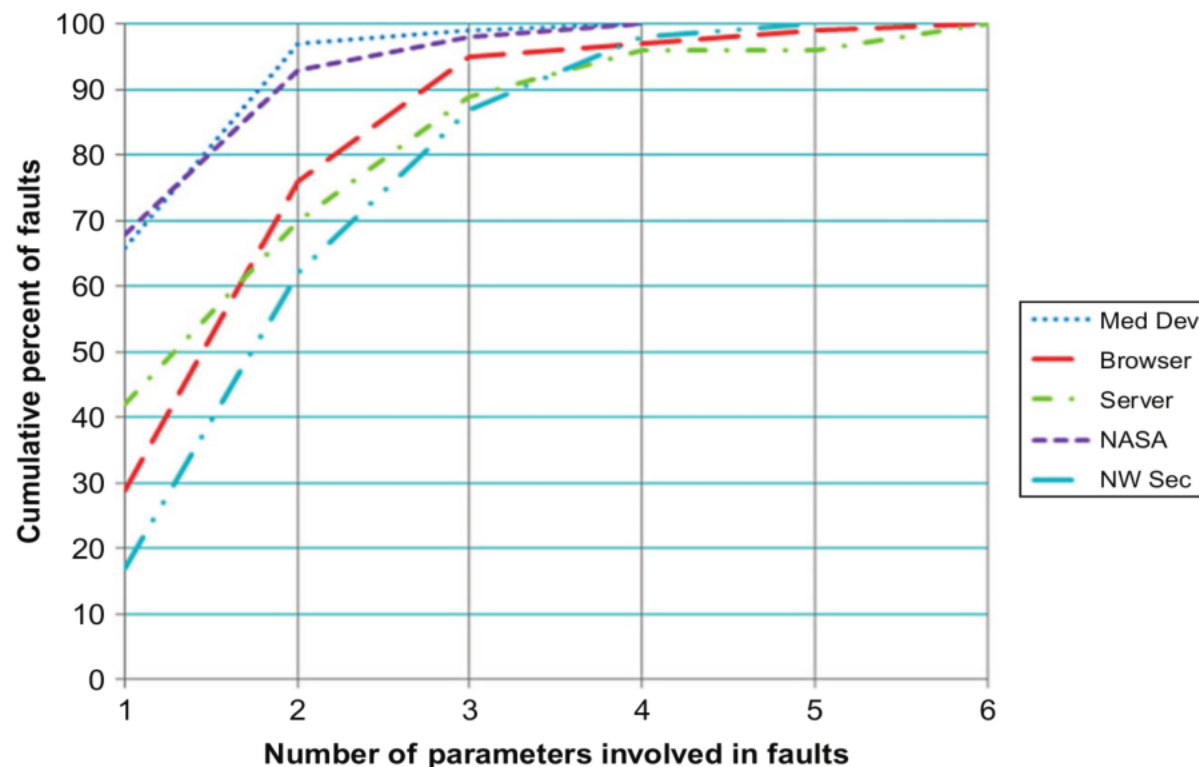
Combinatorial Testing in a Nutshell

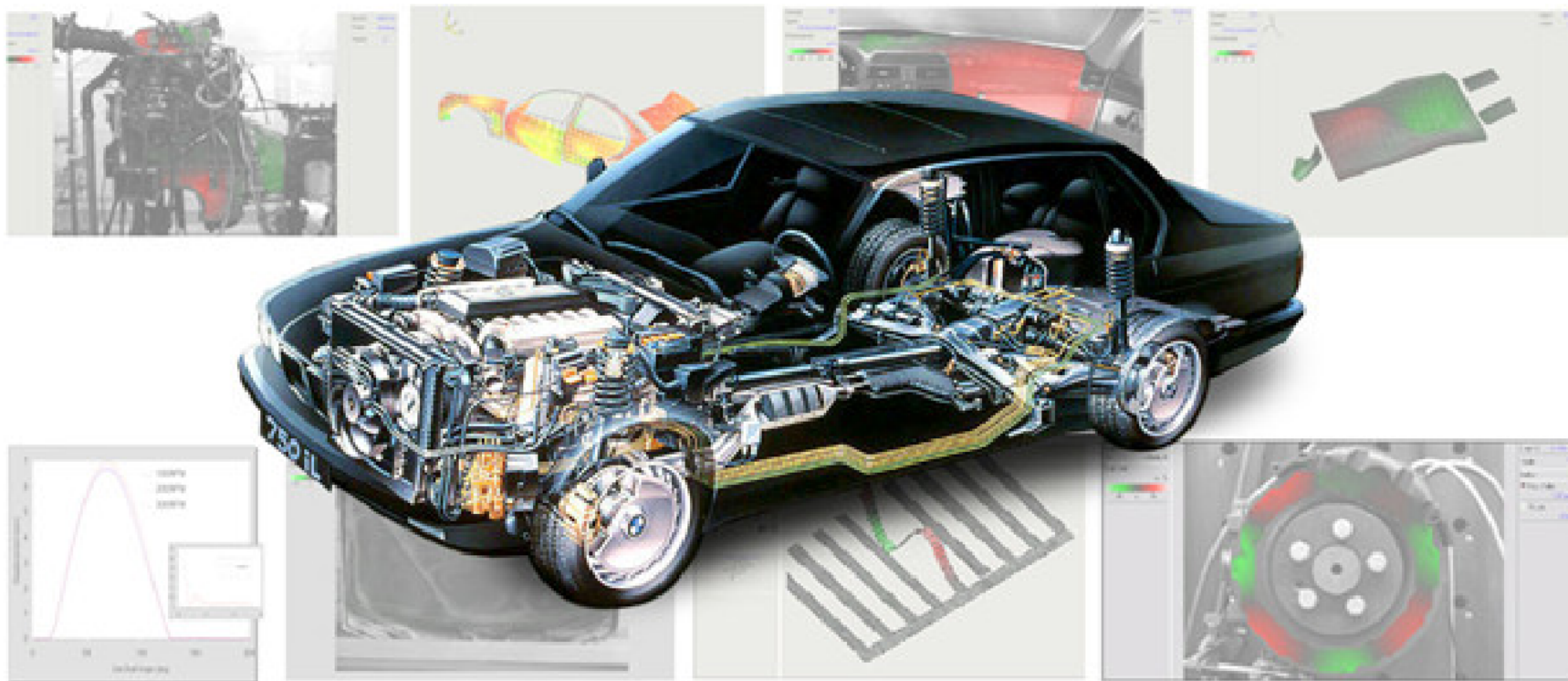
- Suppose we have a system with on-off switches
- 34 switches = $2^{34} = 1.7 \times 10^{10}$ possible settings
- What if we knew no failure involves more than 3 switch settings interacting?
 - If only 3-way combinations, need only 30 tests
 - If only 4-way combinations, need only 83 tests



Combinatorial Testing in a Nutshell

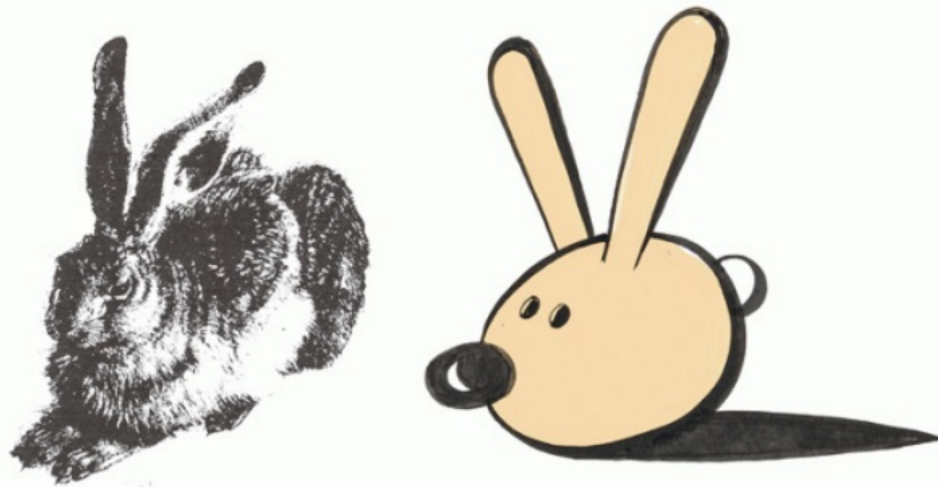
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Composed SUT

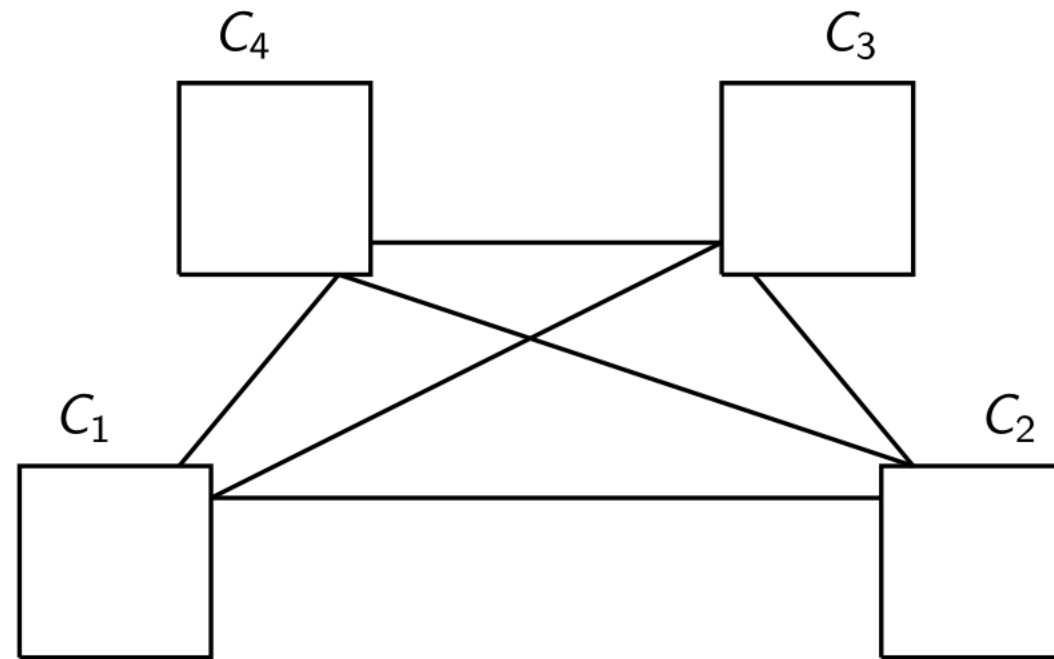


Figure: Composed SUT, with components C_1 , C_2 , C_3 , C_4

C_1		C_2			C_3			C_4		
a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3

Table: Corresponding IPM: 4 vs. 11 parameters

Composed SUT

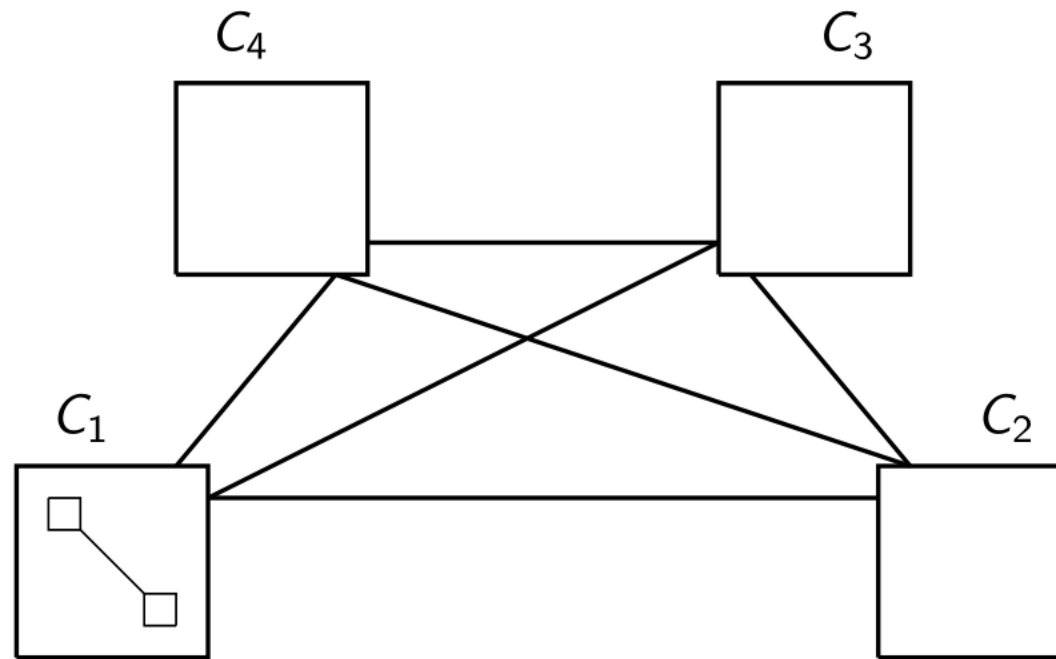


Figure: Composed SUT, with components C_1 , C_2 , C_3 , C_4

C_1		C_2			C_3			C_4		
a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3

Table: Corresponding IPM: 4 vs. 11 parameters

Composed SUT

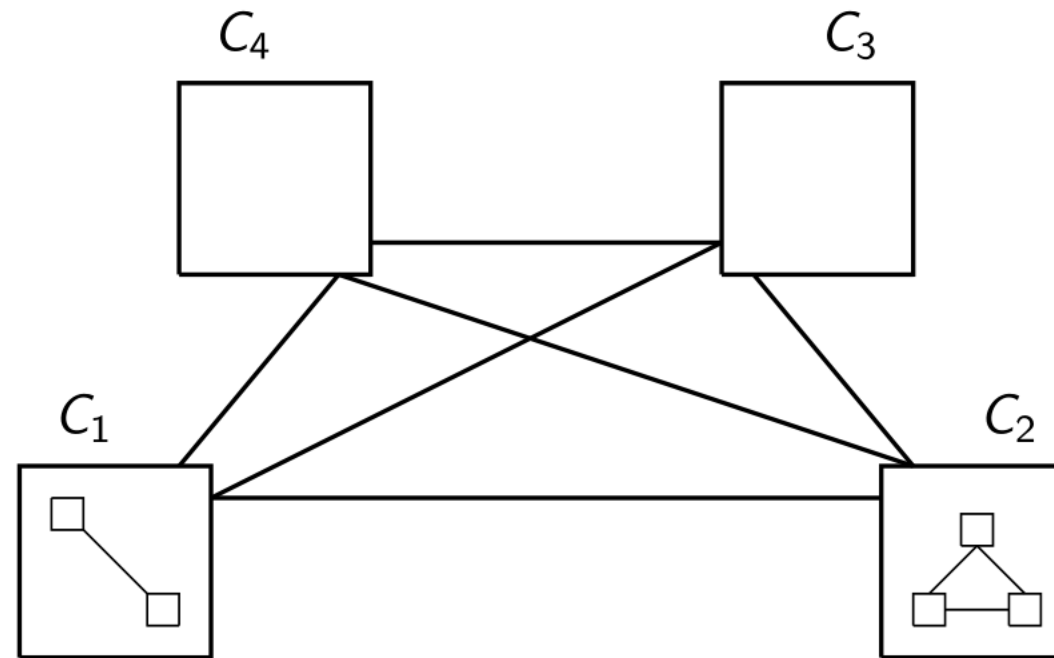


Figure: Composed SUT, with components C_1 , C_2 , C_3 , C_4

C_1		C_2			C_3			C_4		
a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3

Table: Corresponding IPM: 4 vs. 11 parameters

Composed SUT

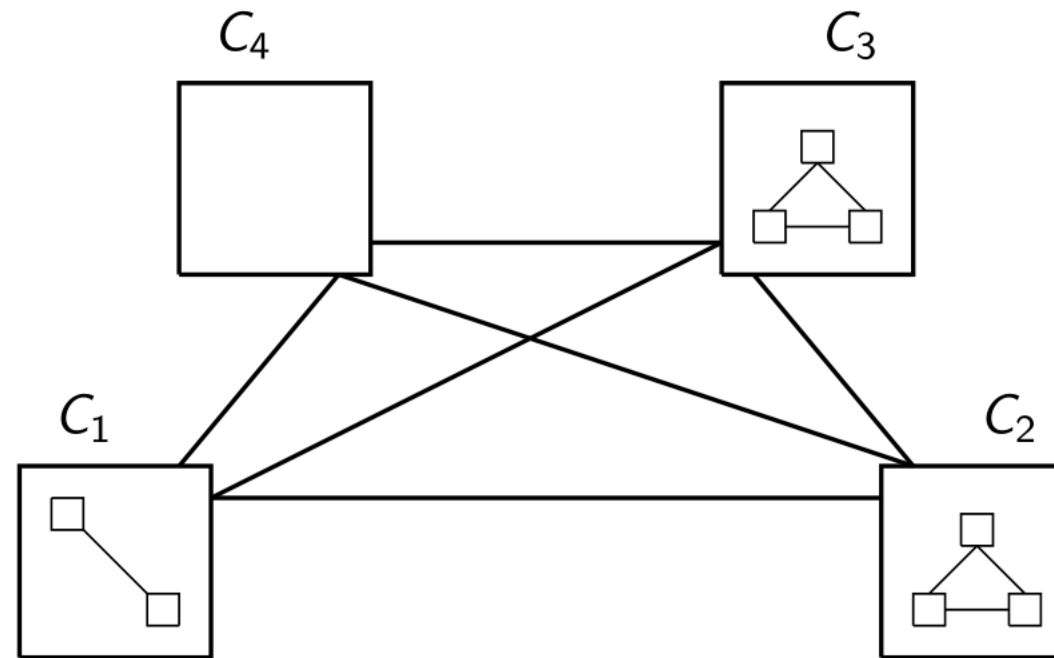


Figure: Composed SUT, with components C_1 , C_2 , C_3 , C_4

C_1		C_2			C_3			C_4		
a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3

Table: Corresponding IPM: 4 vs. 11 parameters

Composed SUT

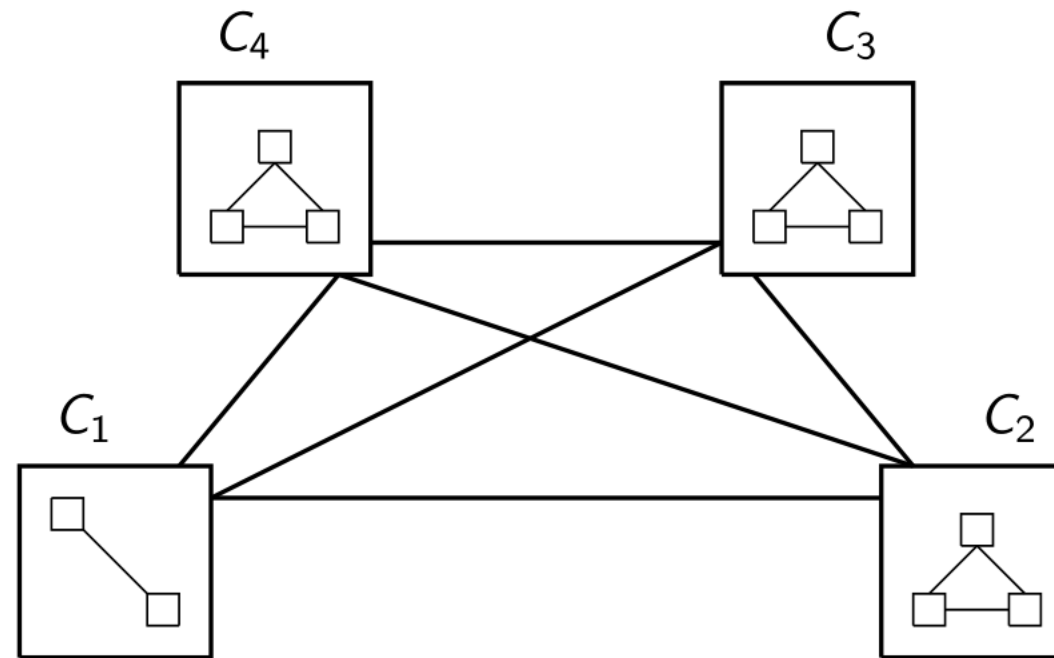


Figure: Composed SUT, with components C_1 , C_2 , C_3 , C_4

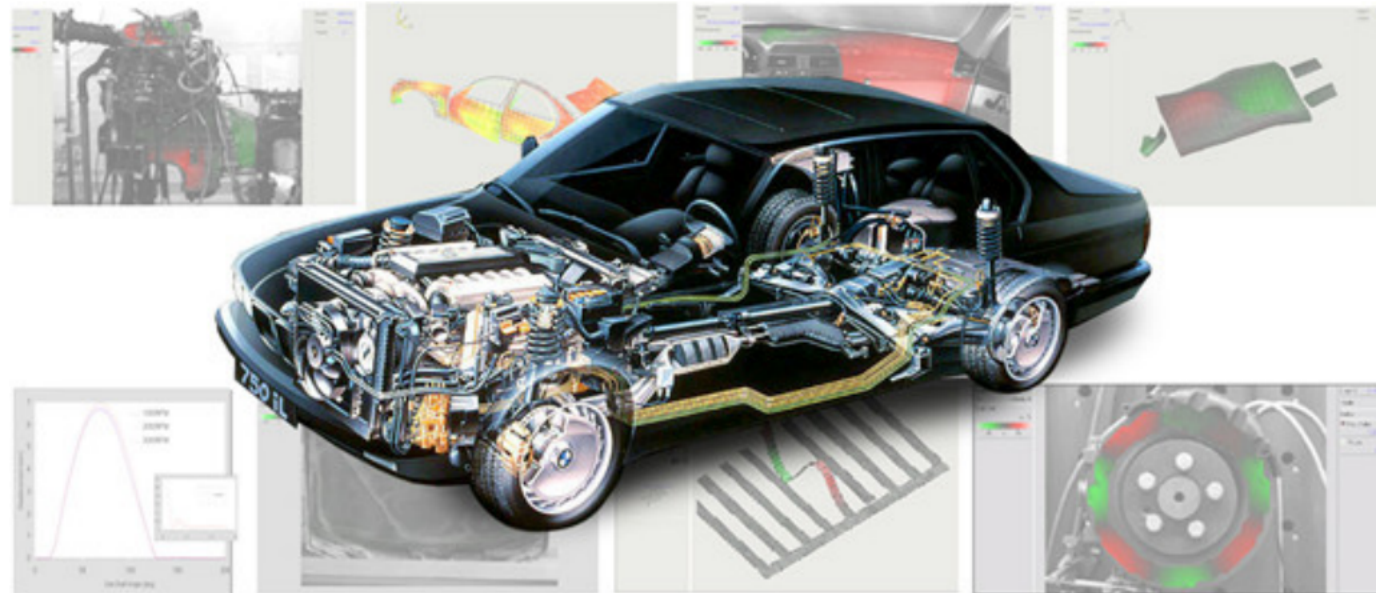
C_1		C_2			C_3			C_4		
a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3

Table: Corresponding IPM: 4 vs. 11 parameters

Composed SUT: Automotive Car

Components of the car

- C_1 : Wheels modelled with two parameters
- C_2 : Engine modelled with three parameters
- C_3 : Infotainment center modelled with three parameters
- C_4 : Communication unit modelled with three parameters



Model of Wheels

Name: IPM-Wheels

producer (enum): Giti (0), Mitas (1), Pirelli (2)

type (boolean): winter (0), summer (1)

A	
a_1	a_2
0	0
0	1
1	0
1	1
2	0
2	1

Wheels	
producer	type
Giti	winter
Giti	summer
Mitas	winter
Mitas	summer
Pirelli	winter
Pirelli	summer

Model of Engine

Name: IPM-Engine

`fuel` (boolean): diesel (0), gas (1)

`drive_mode` (boolean): eco (0), sport (1)

`filter` (boolean): present (0), missing (1)

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

Engine		
<code>fuel</code>	<code>drive_mode</code>	<code>filter</code>
diesel	eco	missing
diesel	sport	present
gas	eco	present
gas	sport	missing

Model of Infotainment Center

Name: IPM-Infotainment-Center

streaming (boolean): true (0), false (1)

audio (boolean): speaker (0), bluetooth (1)

remote_control (boolean): connected (0), disconnected (1)

C		
c ₁	c ₂	c ₃
0	0	1
1	1	1
1	0	0
0	1	0

Infotainment		
streaming	audio	remote
true	speaker	disconnected
false	bluetooth	disconnected
false	speaker	connected
true	bluetooth	connected

Model of Communication Unit

Name: IPM-Communication-Unit

ip_version (boolean): ipv4 (0), ipv6 (1)
connection (boolean): lte (0), wifi (1)
speed (boolean): good (0), bad (1)

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

Communication		
ip_version	connection	speed
ipv4	lte	bad
ipv4	wifi	good
ipv6	lte	good
ipv6	wifi	bad

Plug-In of Seeds into Meta Array

A	
a_1	a_2
0	0
0	1
1	0
1	1
2	0
2	1

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

C		
c_1	c_2	c_3
0	0	1
1	1	1
1	0	0
0	1	0

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

#	$\mathcal{M}$			
	M_1	M_2	M_3	M_4
1	0	0	1	1
2	0	1	2	2
3	0	2	3	3
4	0	3	0	0
5	1	0	2	3
6	1	1	3	0
7	1	2	0	1
8	1	3	1	2
9	2	0	3	2
10	2	1	0	3
11	2	2	1	0
12	2	3	2	1
13	3	0	0	2
14	3	1	1	3
15	3	2	2	0
16	3	3	3	1
17	4	0	0	0
18	4	1	1	1
19	4	2	2	2
20	4	3	3	3
21	5	0	0	0
22	5	1	1	1
23	5	2	2	2
24	5	3	3	3

Plug-In of Seeds into Meta Array

A	
a_1	a_2
0	0
0	1
1	0
1	1
2	0
2	1

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

C		
c_1	c_2	c_3
0	0	1
1	1	1
1	0	0
0	1	0

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

#	$\mathcal{M}$			
	M_1	M_2	M_3	M_4
1	0	0	1	1
2	0	1	2	2
3	0	2	3	3
4	0	3	0	0
5	1	0	2	3
6	1	1	3	0
7	1	2	0	1
8	1	3	1	2
9	2	0	3	2
10	2	1	0	3
11	2	2	1	0
12	2	3	2	1
13	3	0	0	2
14	3	1	1	3
15	3	2	2	0
16	3	3	3	1
17	4	0	0	0
18	4	1	1	1
19	4	2	2	2
20	4	3	3	3
21	5	0	0	0
22	5	1	1	1
23	5	2	2	2
24	5	3	3	3

Plug-In of Seeds into Meta Array

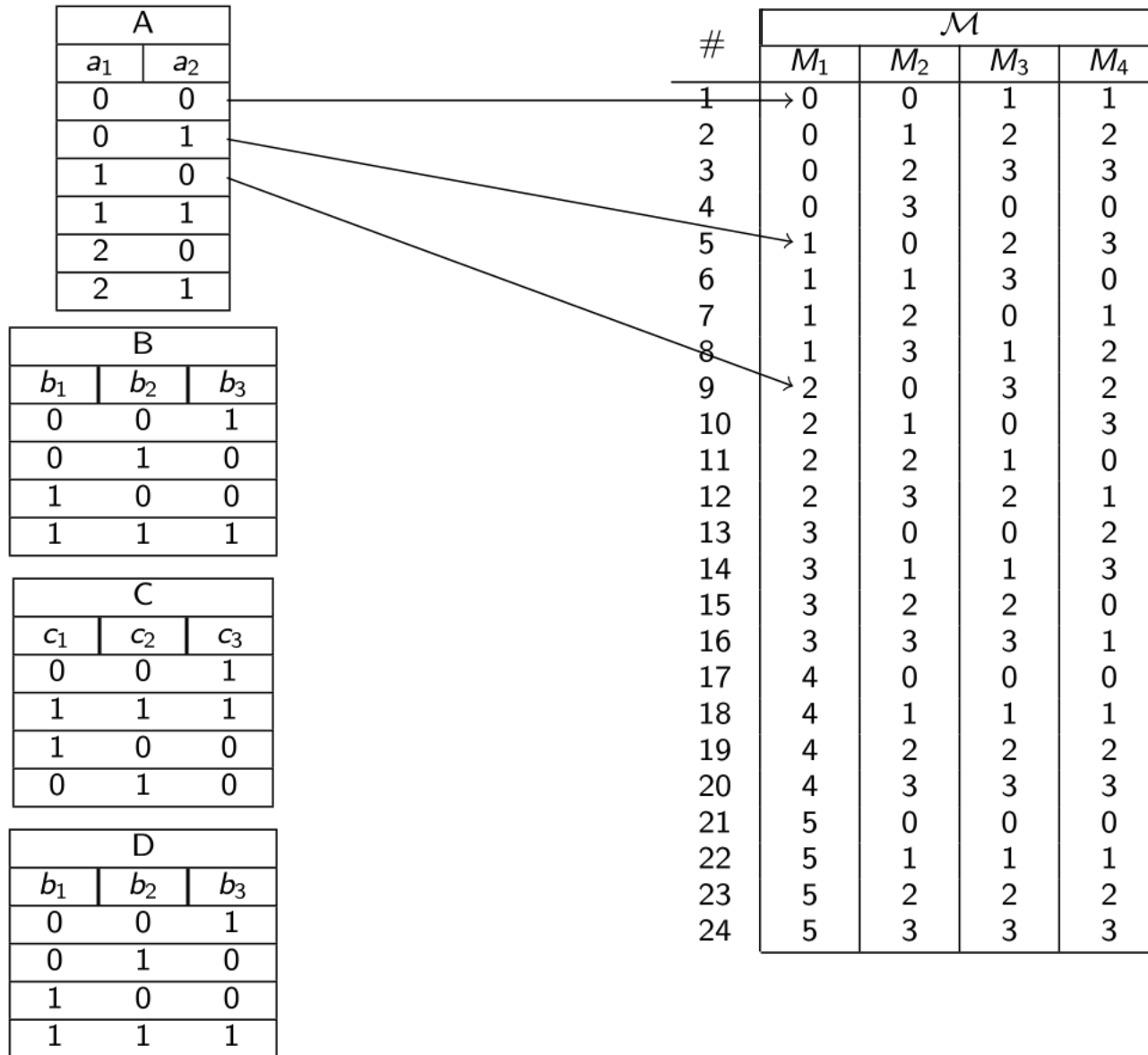
A		#	$\mathcal{M}$			
a_1	a_2		M_1	M_2	M_3	M_4
0	0	1	0	0	1	1
0	1	2	0	1	2	2
1	0	3	0	2	3	3
1	1	4	0	3	0	0
2	0	5	1	0	2	3
2	1	6	1	1	3	0
		7	1	2	0	1
		8	1	3	1	2
		9	2	0	3	2
		10	2	1	0	3
		11	2	2	1	0
		12	2	3	2	1
		13	3	0	0	2
		14	3	1	1	3
		15	3	2	2	0
		16	3	3	3	1
		17	4	0	0	0
		18	4	1	1	1
		19	4	2	2	2
		20	4	3	3	3
		21	5	0	0	0
		22	5	1	1	1
		23	5	2	2	2
		24	5	3	3	3

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

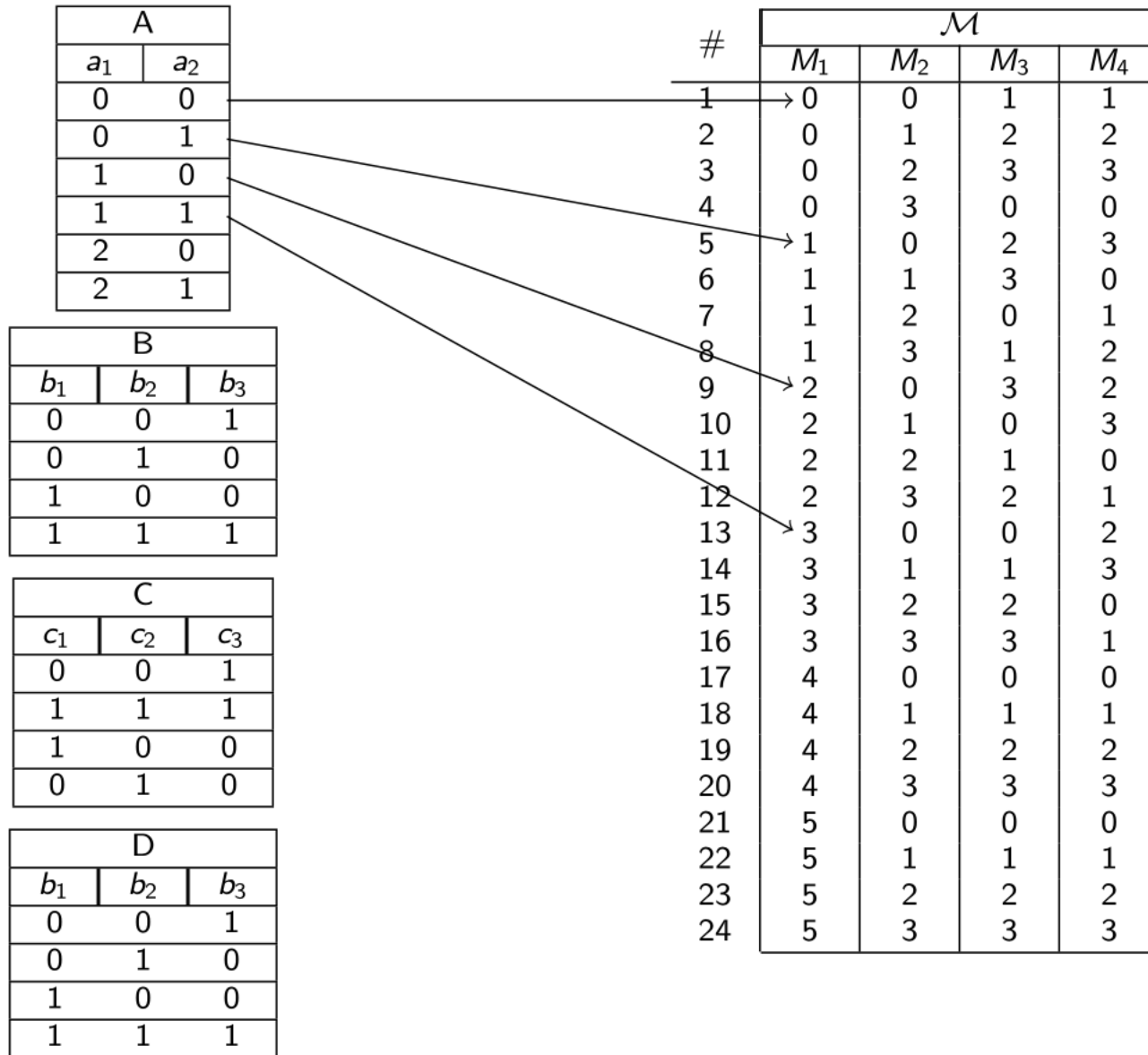
C		
c_1	c_2	c_3
0	0	1
1	1	1
1	0	0
0	1	0

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

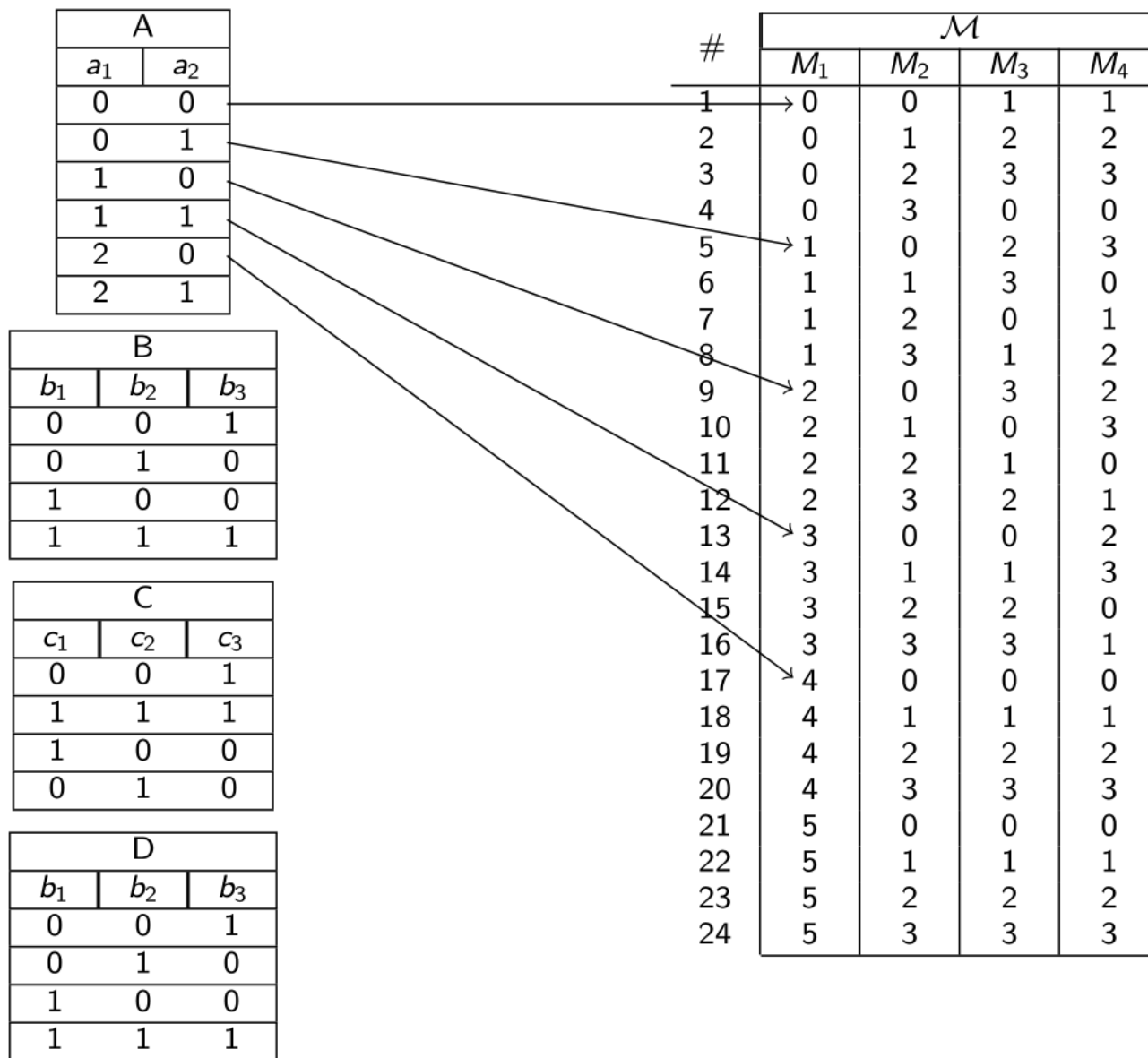
Plug-In of Seeds into Meta Array



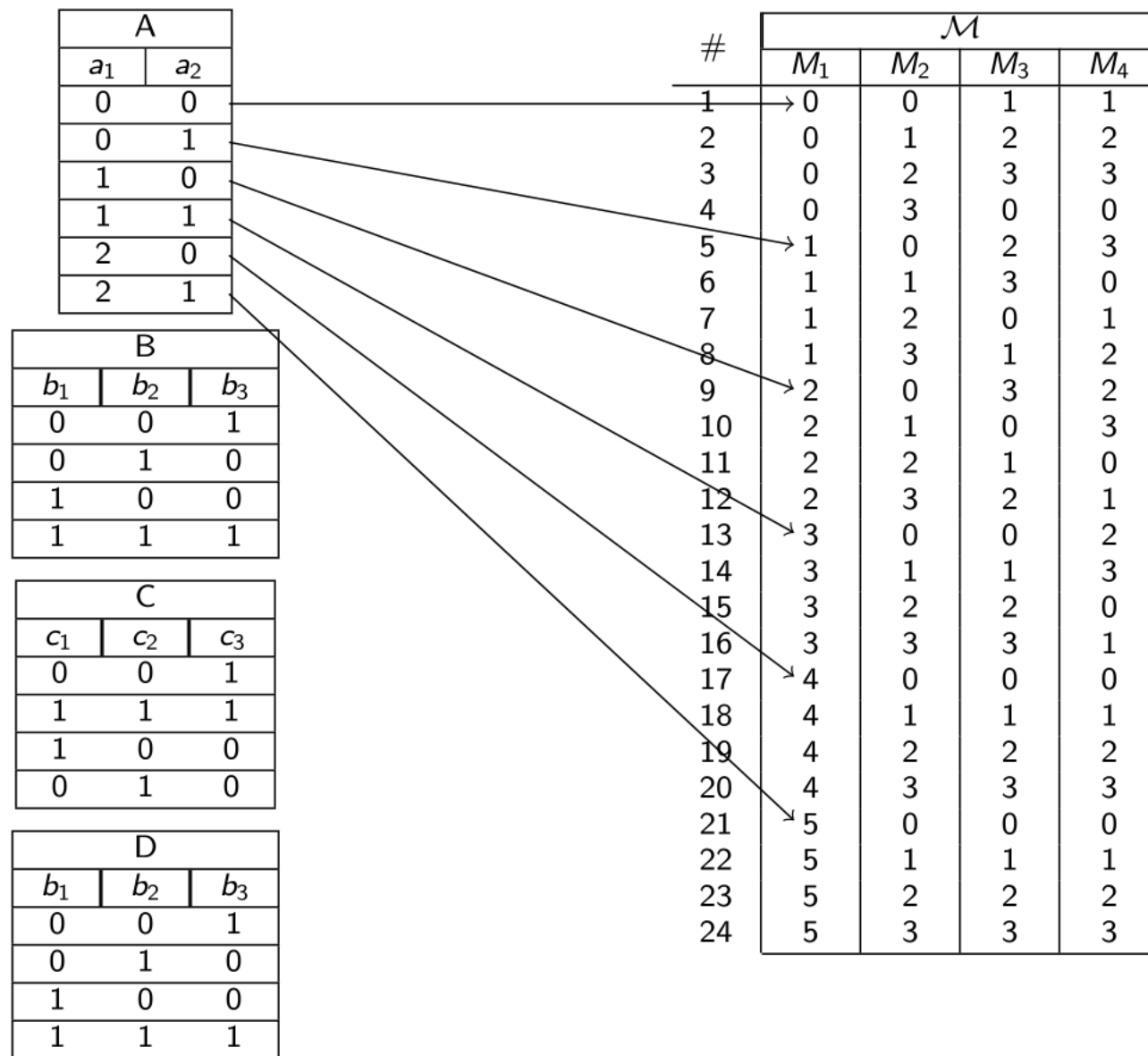
Plug-In of Seeds into Meta Array



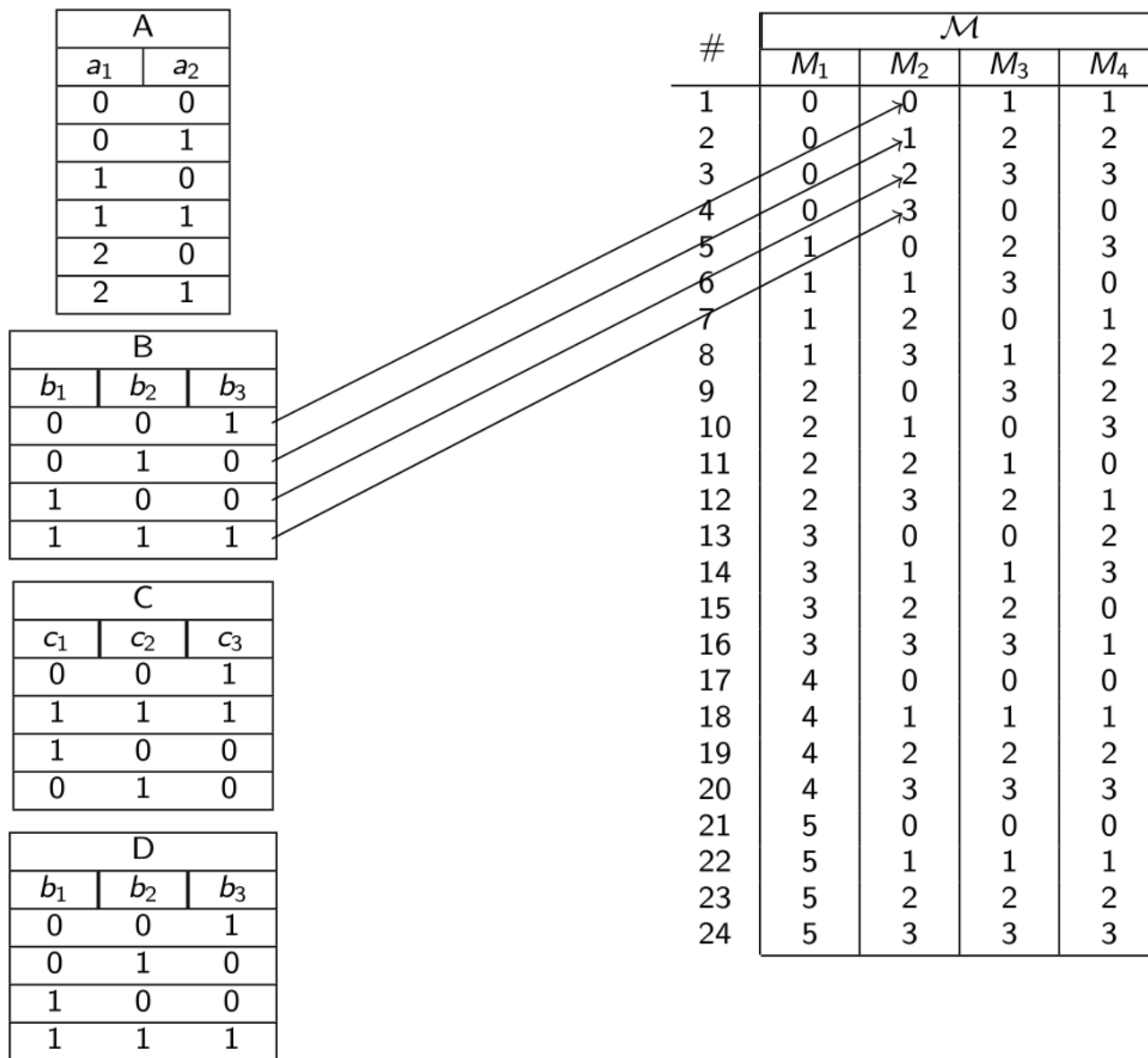
Plug-In of Seeds into Meta Array



Plug-In of Seeds into Meta Array



Plug-In of Seeds into Meta Array



Plug-In of Seeds into Meta Array

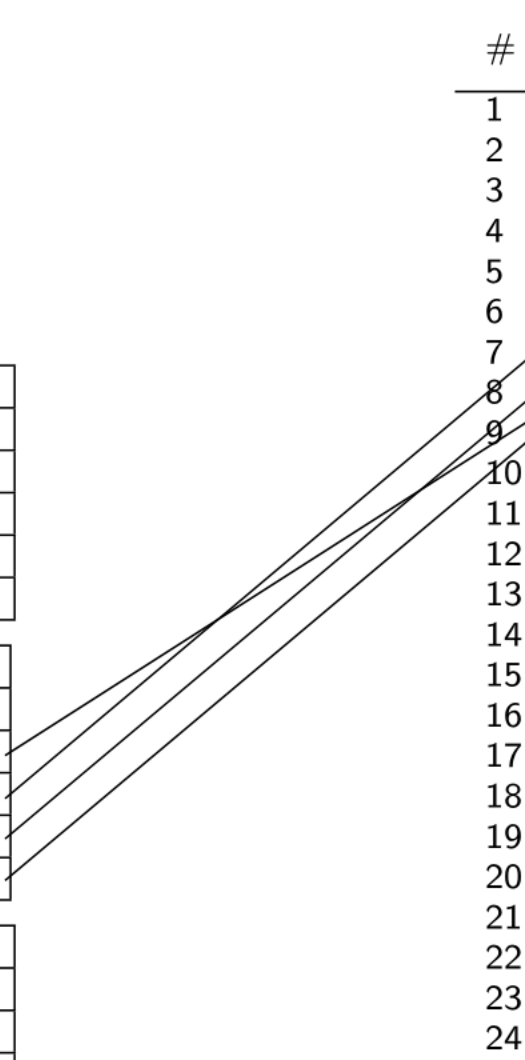
A	
a_1	a_2
0	0
0	1
1	0
1	1
2	0
2	1

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

C		
c_1	c_2	c_3
0	0	1
1	1	1
1	0	0
0	1	0

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

#	$\mathcal{M}$			
	M_1	M_2	M_3	M_4
1	0	0	1	1
2	0	1	2	2
3	0	2	3	3
4	0	3	0	0
5	1	0	2	3
6	1	1	3	0
7	1	2	0	1
8	1	3	1	2
9	2	0	3	2
10	2	1	0	3
11	2	2	1	0
12	2	3	2	1
13	3	0	0	2
14	3	1	1	3
15	3	2	2	0
16	3	3	3	1
17	4	0	0	0
18	4	1	1	1
19	4	2	2	2
20	4	3	3	3
21	5	0	0	0
22	5	1	1	1
23	5	2	2	2
24	5	3	3	3



Plug-In of Seeds into Meta Array

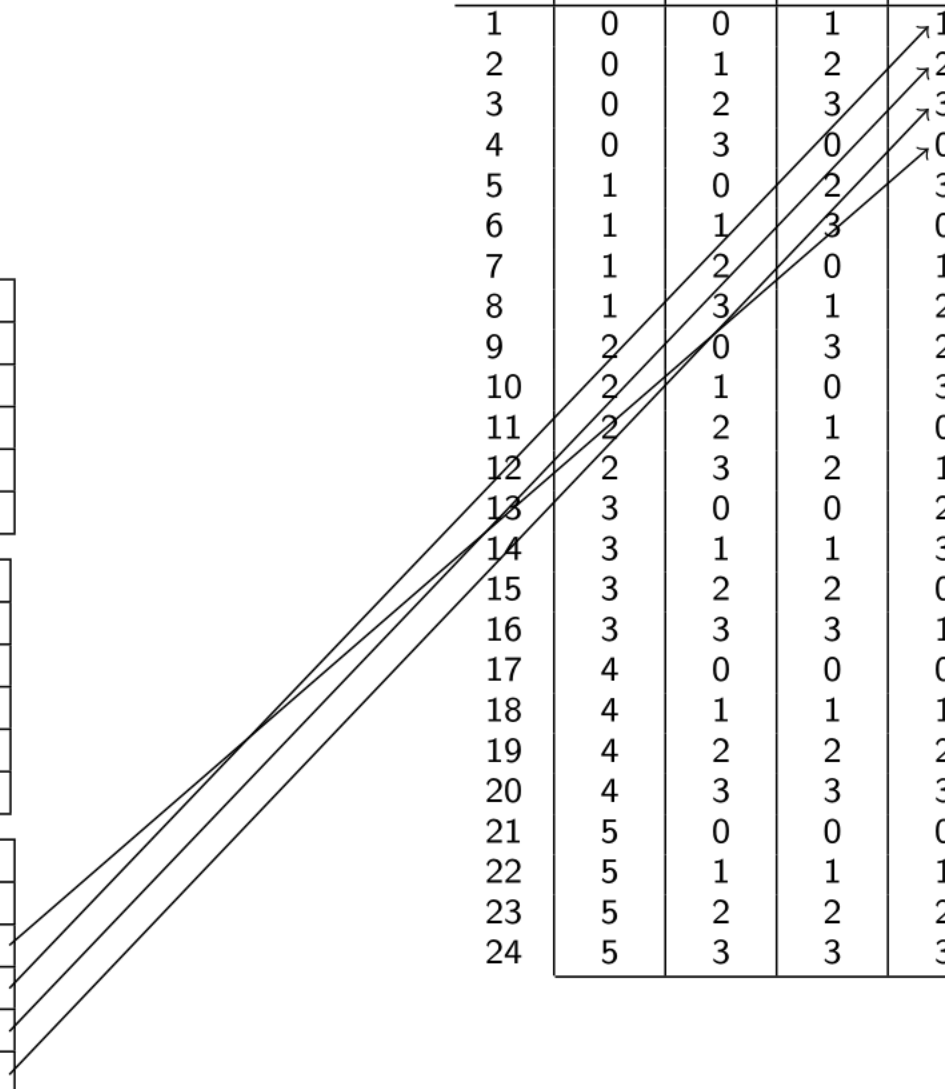
A	
a_1	a_2
0	0
0	1
1	0
1	1
2	0
2	1

B		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

C		
c_1	c_2	c_3
0	0	1
1	1	1
1	0	0
0	1	0

D		
b_1	b_2	b_3
0	0	1
0	1	0
1	0	0
1	1	1

#	$\mathcal{M}$			
	M_1	M_2	M_3	M_4
1	0	0	1	1
2	0	1	2	2
3	0	2	3	3
4	0	3	0	0
5	1	0	2	3
6	1	1	3	0
7	1	2	0	1
8	1	3	1	2
9	2	0	3	2
10	2	1	0	3
11	2	2	1	0
12	2	3	2	1
13	3	0	0	2
14	3	1	1	3
15	3	2	2	0
16	3	3	3	1
17	4	0	0	0
18	4	1	1	1
19	4	2	2	2
20	4	3	3	3
21	5	0	0	0
22	5	1	1	1
23	5	2	2	2
24	5	3	3	3



Resulting Test Suite

#	$\mathcal{R}$										
	a_1	a_2	b_1	b_2	b_3	c_1	c_2	c_3	d_1	d_2	d_3
1	0	0	0	0	1	1	1	1	0	1	0
2	0	0	0	1	0	1	0	0	1	0	0
3	0	0	1	0	0	0	1	0	1	1	1
4	0	0	1	1	1	0	0	1	0	0	1
5	0	1	0	0	1	1	0	0	1	1	1
6	0	1	0	1	0	0	1	0	0	0	1
7	0	1	1	0	0	0	0	1	0	1	0
8	0	1	1	1	1	1	1	1	1	0	0
9	1	0	0	0	1	0	1	0	1	0	0
10	1	0	0	1	0	0	0	1	1	1	1
11	1	0	1	0	0	1	1	1	0	0	1
12	1	0	1	1	1	1	0	0	0	1	0
13	1	1	0	0	1	0	0	1	1	0	0
14	1	1	0	1	0	1	1	1	1	1	1
15	1	1	1	0	0	1	0	0	0	0	1
16	1	1	1	1	1	0	1	0	0	1	0
17	2	0	0	0	1	0	0	1	0	0	1
18	2	0	0	1	0	1	1	1	0	1	0
19	2	0	1	0	0	1	0	0	1	0	0
20	2	0	1	1	1	0	1	0	1	1	1
21	2	1	0	0	1	0	0	1	0	0	1
22	2	1	0	1	0	1	1	1	0	1	0
23	2	1	1	0	0	1	0	0	1	0	0
24	2	1	1	1	1	0	1	0	1	1	1

24 tests compared to the 4 608 of an exhaustive test suite.

Questions - Comments

Thank you for your Attention!



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