New large Condorcet domains on 10 and 11 alternatives, their TRS and Properties

1 Introduction to the properties of Condorcet domains

The distance between two permutations is the minimal number of neighbor inversions needed to convert one permutation to another. A *median graph* is a bidirectional graph formed by all the permutations in a Condorcet domain (CD) as vertices in which two permutations with minimal distance are connected by an edge (i.e. an edge connects two permutations that can be made identical by swapping two neighbor alternatives in one of them)

The width of the CD is the longest possible distance between two permutations in the median graph. A Condorcet domain has *maximal width* if it contains a pair of completely reversed linear orders ($[1, 2, 3, \ldots, n]$ and $[n, n-1, n-2, \ldots, 1]$). A Condorcet domain is *connected* if every two orders from the domain can be obtained from each other by a sequence of transpositions of neighboring alternatives, such that all orders from the connecting path belong to the domain.

Fig. 1 shows the median graph for a Condorcet domain on four alternatives. Each connected permutation only differs at two neighbor positions, and the connection remains unchanged if the alternatives at these positions are exchanged. For instance, permutations 1243 and 1234 will be equivalent if alternatives 3 and 4 are swapped in one of them. The width of this graph is, by definition, six as there are six edges between permutation 1234 and 4321.

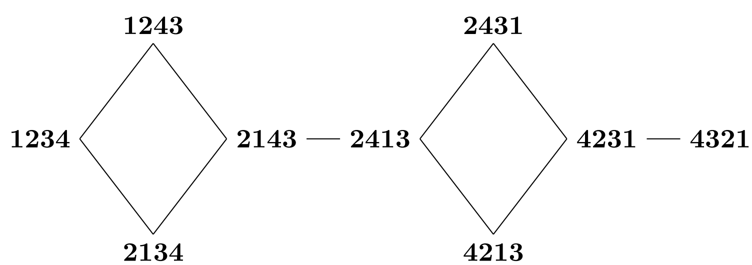

Fig. 1 The median graph for a Condorcet domain on 4 alternatives. The distance between permutations 1234 and 4321 is the longest among all pairs of permutations. The shortest path between them has a length of 6 so the width of this graph is 6.

The definition of the width, radius and centre point of a Condorcet domain is the same as those of their median graph. The width (also called diameter) of a Condorcet domain is the longest possible distance between any two permutations in it. The radius of a Condorcet domain is the minimum distance between the identity permutation and any other permutation within the Condorcet domain. A centre point is a permutation whose distance to the identity permutation is equal to the radius.

In Table 1, we display the sizes, widths, radius, the number of centre points and the number of their isomorphic Condorcet domains for the Fishburn domain on 4 to 13 alternatives. While the median graphs have been extensively discussed in the literature, to the best of our knowledge, the data for the radius and the number of centre points have not been published. The width and radius grow monotonically as the number of alternatives in the graph increases. The number of centre points generally follows that trend, but there are 93 centre points in the 11 alternative median graph, which is less than the 10 alternative ones. Not all Fishburn domains shown in this table have the same number of isomorphic Condorcet domains as their sizes. The number of isomorphic Condorcet domains for Fishburn domains on the odd number of alternatives is only half of their size.

Table 1 The size, width, radius, the number of centre points, and the number of isomorphic Condorcet domain of the Fishburn domains on 4 to 13 alternatives.

Num of alternatives (n)	4	5	6	7	8	9	10	11	12	13
Size	9	20	45	100	222	488	1069	2324	5034	10840
Width	6	10	15	21	28	36	45	55	66	78
Radius	3	5	8	11	14	18	23	28	33	39
Num of centre points	1	2	6	10	9	16	57	102	93	172
Num of isomorphic CDs	9	10	45	50	222	244	1069	1162	5034	5420

2 The properties of the n=10 CD of size 1082

We found 242 CDs on 10 alternatives larger than the Fishburn domain and by definition, all the median graphs built upon these CDs are connected. So far, the CDs on 10 alternatives with the highest width and radius are created by the alternating scheme, which has a width of 45 and a radius of 23. Although the sizes of the newly found large CDs are larger than those of the Fishburn domain, their widths and radius are smaller. The number of centre points in the graph for the Fishburn domain is 57, the same as the domains of size 1070 and 1080, the smallest and the largest CDs that broke the record found by our search algorithm.

Table 2 The size and the number of equivalent CDs of the 10 alternative large CDs we found, and the width of, the radius of, and the number of centre points in their median graph.

New CD size	1070	1071	1072	1074	1078	1079	1082
Width	41	43	41	42	42	43	41
Radius	21	22	21	21	21	22	21
Num of centre points	57	56	38	24	28	56	57
Num of isomorphic CDs	1070	1071	1072	1074	1078	1079	1082

3 The properties of the n=11 CD of size 2349

We discovered 543 CDs in 5 different sizes larger than the Fishburn domain on 11 alternatives. Their properties are presented in Table 3. The largest CD among them is of size 2349, which contains 25 more permutations than the Fishburn domain, which is of size 2324. The width and radius of all the new CDs are less than those of the Fishburn domain. However, the number of all the equivalent CDs of the newly discovered CDs is the same as their size, differing from the Fishburn domain, where the number of isomorphic CDs is exactly half its size.

Table 3 The size and the number of isomorphic CDs of the record-breaking CDs for 11 alternatives and the width, the radius, and the number of centre points in their median graph.

New CD size	2328	2329	2334	2337	2349
Width	53	51	51	52	52
Radius	27	26	26	26	26
Num of centre points	102	102	102	51	51
Num of isomorphic CDs	2328	2329	2334	2337	2349

4 The triples and their never condition (NC) for the n=10 CD of size 1082

Table 4 The TRS that led to the CD of size 1082 on 10 alternatives. The ordering of the triples displayed is another static ordering that differs from the ordering used in the search algorithm and is defined such that (x_1, y_1, z_1) is before (x_2, y_2, z_2) if $x_1 \leq x_2$ and $y_1 \leq y_2$ and $z_1 \leq z_2$ out of consideration for the ease of looking up the table manually. There are 1082 isomorphic versions of this CD. The 10 alternative CD built by these never conditions is presented in Sect. 6.

Triples	**NC**	**Triples**	**NC**	**Triples**	**NC**	**Triples**	**NC**
(1, 2, 3)	2N3	(1, 7, 8)	1N3	(2, 7, 10)	1N3	(4, 6, 7)	3N1
(1, 2, 4)	2N3	(1, 7, 9)	1N3	(2, 8, 9)	1N3	(4, 6, 8)	3N1
(1, 2, 5)	1N3	(1, 7, 10)	1N3	(2, 8, 10)	1N3	(4, 6, 9)	1N3
(1, 2, 6)	1N3	(1, 8, 9)	2N1	(2, 9, 10)	3N1	(4, 6, 10)	3N1
(1, 2, 7)	1N3	(1, 8, 10)	2N1	(3, 4, 5)	1N3	(4, 7, 8)	3N1
(1, 2, 8)	3N1	(1, 9, 10)	3N1	(3, 4, 6)	1N3	(4, 7, 9)	1N3
(1, 2, 9)	2N3	(2, 3, 4)	2N3	(3, 4, 7)	1N3	(4, 7, 10)	3N1
(1, 2, 10)	2N3	(2, 3, 5)	1N3	(3, 4, 8)	1N3	(4, 8, 9)	1N3
(1, 3, 4)	2N3	(2, 3, 6)	1N3	(3, 4, 9)	1N3	(4, 8, 10)	3N1
(1, 3, 5)	1N3	(2, 3, 7)	1N3	(3, 4, 10)	1N3	(4, 9, 10)	1N3
(1, 3, 6)	1N3	(2, 3, 8)	1N3	(3, 5, 6)	3N1	(5, 6, 7)	3N1
(1, 3, 7)	1N3	(2, 3, 9)	3N1	(3, 5, 7)	3N1	(5, 6, 8)	1N3
(1, 3, 8)	3N1	(2, 3, 10)	3N1	(3, 5, 8)	3N1	(5, 6, 9)	2N1
(1, 3, 9)	3N1	(2, 4, 5)	1N3	(3, 5, 9)	1N3	(5, 6, 10)	1N3
(1, 3, 10)	3N1	(2, 4, 6)	1N3	(3, 5, 10)	3N1	(5, 7, 8)	1N3
(1, 4, 5)	1N3	(2, 4, 7)	1N3	(3, 6, 7)	3N1	(5, 7, 9)	2N1
(1, 4, 6)	1N3	(2, 4, 8)	1N3	(3, 6, 8)	3N1	(5, 7, 10)	1N3
(1, 4, 7)	1N3	(2, 4, 9)	3N1	(3, 6, 9)	1N3	(5, 8, 9)	2N1
(1, 4, 8)	3N1	(2, 4, 10)	3N1	(3, 6, 10)	3N1	(5, 8, 10)	2N1
(1, 4, 9)	3N1	(2, 5, 6)	3N1	(3, 7, 8)	3N1	(5, 9, 10)	3N1
(1, 4, 10)	3N1	(2, 5, 7)	3N1	(3, 7, 9)	1N3	(6, 7, 8)	2N1
(1, 5, 6)	3N1	(2, 5, 8)	3N1	(3, 7, 10)	3N1	(6, 7, 9)	2N1
(1, 5, 7)	3N1	(2, 5, 9)	1N3	(3, 8, 9)	1N3	(6, 7, 10)	2N1
(1, 5, 8)	1N3	(2, 5, 10)	1N3	(3, 8, 10)	3N1	(6, 8, 9)	2N1
(1, 5, 9)	1N3	(2, 6, 7)	3N1	(3, 9, 10)	1N3	(6, 8, 10)	2N1
(1, 5, 10)	1N3	(2, 6, 8)	3N1	(4, 5, 6)	3N1	(6, 9, 10)	3N1
(1, 6, 7)	3N1	(2, 6, 9)	1N3	(4, 5, 7)	3N1	(7, 8, 9)	2N1
(1, 6, 8)	1N3	(2, 6, 10)	1N3	(4, 5, 8)	3N1	(7, 8, 10)	2N1
(1, 6, 9)	1N3	(2, 7, 8)	3N1	(4, 5, 9)	1N3	(7, 9, 10)	3N1
(1, 6, 10)	1N3	(2, 7, 9)	1N3	(4, 5, 10)	3N1	(8, 9, 10)	3N1

5 The triples and their never condition for the n=11 CD of size 2349

Table 5 The TRS that constructed CD of size 2349 on 11 alternatives. The 11 alternative CD built by these never conditions is presented in Sect. 6.

Triples	NC	Triples	NC	Triples	NC	Triples	NC
(1, 2, 3)	1N3	(1, 9, 10)	3N1	(3, 4, 8)	3N1	(4, 8, 11)	2N1
(1, 2, 4)	2N3	(1, 9, 11)	3N1	(3, 4, 9)	1N3	(4, 9, 10)	3N1
(1, 2, 5)	2N3	(1, 10, 11)	2N1	(3, 4, 10)	3N1	(4, 9, 11)	2N3
(1, 2, 6)	2N3	(2, 3, 4)	1N3	(3, 4, 11)	1N3	(4, 10, 11)	2N1
(1, 2, 7)	3N1	(2, 3, 5)	1N3	(3, 5, 6)	3N1	(5, 6, 7)	2N1
(1, 2, 8)	1N3	(2, 3, 6)	1N3	(3, 5, 7)	3N1	(5, 6, 8)	2N1
(1, 2, 9)	1N3	(2, 3, 7)	3N1	(3, 5, 8)	3N1	(5, 6, 9)	2N1
(1, 2, 10)	1N3	(2, 3, 8)	3N1	(3, 5, 9)	1N3	(5, 6, 10)	2N1
(1, 2, 11)	1N3	(2, 3, 9)	2N3	(3, 5, 10)	3N1	(5, 6, 11)	2N1
(1, 3, 4)	1N3	(2, 3, 10)	3N1	(3, 5, 11)	1N3	(5, 7, 8)	2N1
(1, 3, 5)	1N3	(2, 3, 11)	2N3	(3, 6, 7)	3N1	(5, 7, 9)	2N1
(1, 3, 6)	1N3	(2, 4, 5)	3N1	(3, 6, 8)	3N1	(5, 7, 10)	2N1
(1, 3, 7)	1N3	(2, 4, 6)	3N1	(3, 6, 9)	1N3	(5, 7, 11)	2N1
(1, 3, 8)	3N1	(2, 4, 7)	1N3	(3, 6, 10)	3N1	(5, 8, 9)	2N1
(1, 3, 9)	2N3	(2, 4, 8)	1N3	(3, 6, 11)	1N3	(5, 8, 10)	2N1
(1, 3, 10)	3N1	(2, 4, 9)	1N3	(3, 7, 8)	3N1	(5, 8, 11)	2N1
(1, 3, 11)	2N3	(2, 4, 10)	1N3	(3, 7, 9)	1N3	(5, 9, 10)	3N1
(1, 4, 5)	3N1	(2, 4, 11)	1N3	(3, 7, 10)	3N1	(5, 9, 11)	2N3
(1, 4, 6)	3N1	(2, 5, 6)	3N1	(3, 7, 11)	1N3	(5, 10, 11)	2N1
(1, 4, 7)	3N1	(2, 5, 7)	1N3	(3, 8, 9)	1N3	(6, 7, 8)	2N1
(1, 4, 8)	1N3	(2, 5, 8)	1N3	(3, 8, 10)	3N1	(6, 7, 9)	2N1
(1, 4, 9)	1N3	(2, 5, 9)	1N3	(3, 8, 11)	1N3	(6, 7, 10)	2N1
(1, 4, 10)	1N3	(2, 5, 10)	1N3	(3, 9, 10)	1N3	(6, 7, 11)	2N1
(1, 4, 11)	1N3	(2, 5, 11)	1N3	(3, 9, 11)	3N1	(6, 8, 9)	2N1
(1, 5, 6)	3N1	(2, 6, 7)	1N3	(3, 10, 11)	1N3	(6, 8, 10)	2N1
(1, 5, 7)	3N1	(2, 6, 8)	1N3	(4, 5, 6)	3N1	(6, 8, 11)	2N1
(1, 5, 8)	1N3	(2, 6, 9)	1N3	(4, 5, 7)	1N3	(6, 9, 10)	3N1
(1, 5, 9)	1N3	(2, 6, 10)	1N3	(4, 5, 8)	1N3	(6, 9, 11)	2N3
(1, 5, 10)	1N3	(2, 6, 11)	1N3	(4, 5, 9)	2N1	(6, 10, 11)	2N1
(1, 5, 11)	1N3	(2, 7, 8)	2N1	(4, 5, 10)	1N3	(7, 8, 9)	2N1
(1, 6, 7)	3N1	(2, 7, 9)	2N1	(4, 5, 11)	2N1	(7, 8, 10)	2N1
(1, 6, 8)	1N3	(2, 7, 10)	2N1	(4, 6, 7)	1N3	(7, 8, 11)	2N1
(1, 6, 9)	1N3	(2, 7, 11)	2N1	(4, 6, 8)	1N3	(7, 9, 10)	3N1
(1, 6, 10)	1N3	(2, 8, 9)	2N1	(4, 6, 9)	2N1	(7, 9, 11)	2N3
(1, 6, 11)	1N3	(2, 8, 10)	2N1	(4, 6, 10)	1N3	(7, 10, 11)	2N1
(1, 7, 8)	1N3	(2, 8, 11)	2N1	(4, 6, 11)	2N1	(8, 9, 10)	3N1
(1, 7, 9)	1N3	(2, 9, 10)	3N1	(4, 7, 8)	2N1	(8, 9, 11)	2N3
(1, 7, 10)	1N3	(2, 9, 11)	3N1	(4, 7, 9)	2N1	(8, 10, 11)	2N1
(1, 7, 11)	1N3	(2, 10, 11)	2N1	(4, 7, 10)	2N1	(9, 10, 11)	1N3
(1, 8, 9)	2N1	(3, 4, 5)	3N1	(4, 7, 11)	2N1		
(1, 8, 10)	2N1	(3, 4, 6)	3N1	(4, 8, 9)	2N1		
(1, 8, 11)	2N1	(3, 4, 7)	3N1	(4, 8, 10)	2N1		

6 The Condorcet domains

The large Condorcet domains we discovered for 10 and 11 alternatives are demonstrated here. We use hexadecimal numbers A and B to represent the domain's decimal numbers 10 and 11.

The Condorcet domain of size 1082 on 10 alternatives

123456789A 12345678A9 123456798A 12345679A8 123456978A 12345697A8 1234569A78 1234569A87 123459678A 12345967A8
1234596A78 1234596A87 123459A678 123459A687 123459A867 123459A876 123495678A 12349567A8 1234956A78 1234956A87
123495A678 123495A687 123495A867 123495A876 123496578A 12349657A8 1234965A78 1234965A87 123496758A 12349675A8
12349A5678 12349A5687 12349A5867 12349A5876 12349A8567 12349A8576 123546789A 12354678A9 123546798A 12354679A8
123546978A 12354697A8 1235469A78 1235469A87 123549678A 12354967A8 1235496A78 1235496A87 123549A678 123549A687
123549A867 123549A876 123564789A 12356478A9 123564798A 12356479A8 123564978A 12356497A8 1235649A78 1235649A87
123567489A 12356748A9 123567498A 12356749A8 123567849A 12356784A9 1235678A49 123945678A 12394567A8 1239456A78

1239456A87 123945A678 123945A687 123945A867 123945A876 123946578A 12394657A8 1239465A78 1239465A87 123946758A
12394675A8 12394A5678 12394A5687 12394A5867 12394A5876 12394A8567 12394A8576 125346789A 12534678A9 125346798A
12534679A8 125346978A 12534697A8 1253469A78 1253469A87 125349678A 12534967A8 1253496A78 1253496A87 125349A678
125349A687 125349A867 125349A876 125364789A 12536478A9 125364798A 12536479A8 125364978A 12536497A8 1253649A78
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129345A867 129345A876 129346578A 12934657A8 1293465A78 1293465A87 129346758A 12934675A8 12934A5678 12934A5687
12934A5867 12934A5876 12934A8567 12934A8576 152346789A 15234678A9 152346798A 15234679A8 152346978A 15234697A8
1523469A78 1523469A87 152349678A 15234967A8 1523496A78 1523496A87 152349A678 152349A687 152349A867 152349A876
152364789A 15236478A9 152364798A 15236479A8 152364978A 15236497A8 1523649A78 1523649A87 152367489A 15236748A9
152367498A 15236749A8 152367849A 15236784A9 1523678A49 152634789A 15263478A9 152634798A 15263479A8 152634978A
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1567823A49 156782A349 213456789A 21345678A9 213456798A 21345679A8 213456978A 21345697A8 2134569A78 2134569A87
213459678A 21345967A8 2134596A78 2134596A87 213459A678 213459A687 213459A867 213459A876 213495678A 21349567A8
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213546798A 21354679A8 213546978A 21354697A8 2135469A78 2135469A87 213549678A 21354967A8 2135496A78 2135496A87
213549A678 213549A687 213549A867 213549A876 213564789A 21356478A9 213564798A 21356479A8 213564978A 21356497A8
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21394567A8 2139456A78 2139456A87 213945A678 213945A687 213945A867 213945A876 213946578A 21394657A8 2139465A78
2139465A87 213946758A 21394675A8 21394A5678 21394A5687 21394A5867 21394A5876 21394A8567 21394A8576 215346789A
21534678A9 215346798A 21534679A8 215346978A 21534697A8 2153469A78 2153469A87 215349678A 21534967A8 2153496A78
2153496A87 215349A678 215349A687 215349A867 215349A876 215364789A 21536478A9 215364798A 21536479A8 215364978A
21536497A8 2153649A78 2153649A87 215367489A 21536748A9 215367498A 21536749A8 215367849A 21536784A9 2153678A49
215634789A 21563478A9 215634798A 21563479A8 215634978A 21563497A8 2156349A78 2156349A87 215637489A 21563748A9
215637498A 21563749A8 215637849A 21563784A9 2156378A49 215673489A 21567348A9 215673498A 21567349A8 215673849A
21567384A9 2156738A49 215678349A 21567834A9 2156783A49 215678A349 219345678A 21934567A8 2193456A78 2193456A87
219345A678 219345A687 219345A867 219345A876 219346578A 21934657A8 2193465A78 2193465A87 219346758A 21934675A8
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231456978A 23145697A8 2314569A78 2314569A87 231459678A 23145967A8 2314596A78 2314596A87 231459A678 231459A687
231459A867 231459A876 231495678A 23149567A8 2314956A78 2314956A87 231495A678 231495A687 231495A867 231495A876
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231549678A 23154967A8 2315496A78 2315496A87 231549A678 231549A687 231549A867 231549A876 231564789A 23156478A9
231564798A 23156479A8 231564978A 23156497A8 2315649A78 2315649A87 231567489A 23156748A9 231567498A 23156749A8
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