



## Sistemas Reticulados

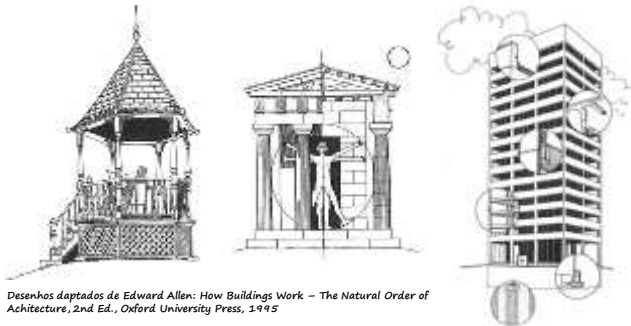
Professores  
Ruy Marcelo O. Pauletti & Leila Meneghetti Valverdes  
2º Semestre 2016

**Sistema:** conjunto de elementos relacionados funcionalmente, dotado de um caráter unitário, que se descreve por seu comportamento e sua estrutura.



### Sistema Estrutural:

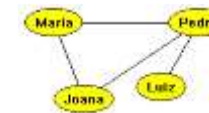
conjunto de elementos físicos, relacionados funcionalmente, dotado de um caráter unitário, que se destina à manutenção da forma, sob a ação de forças de natureza diversa.



Desenhos adaptados de Edward Allen: How Buildings Work – The Natural Order of Architecture, 2nd Ed., Oxford University Press, 1995



### Grafos:



Diferentes disposições geométricas de um mesmo grafo:



### Sistemas Reticulados:

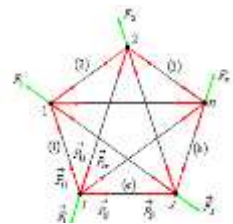
Grafos em que a disposição geométrica dos elementos é relevante



## Sistemas Estruturais Reticulados:

Sistemas cujos elementos podem ser bem representados por um grafo composto por pontos chamados nós, interconectados por linhas materiais que transmitem forças e momentos.

*Treliças, Redes de Cabos, 'Tensigrities'*  
(*'Sistemas de Forças Centrais'*):



*Equilíbrio do Sistema:*

$$\vec{F}_i + \sum_{j=1}^n N_{ij} \frac{\vec{x}_j - \vec{x}_i}{\|\vec{x}_j - \vec{x}_i\|} = \vec{0} \quad , \quad i = 1, 2, \dots, n$$



## Redes



Pavilhão Brasileiro da Expo Milão 2015  
Studio Arthur Casas + Atelier Marko Brajovic



## Sistema Arquitrave

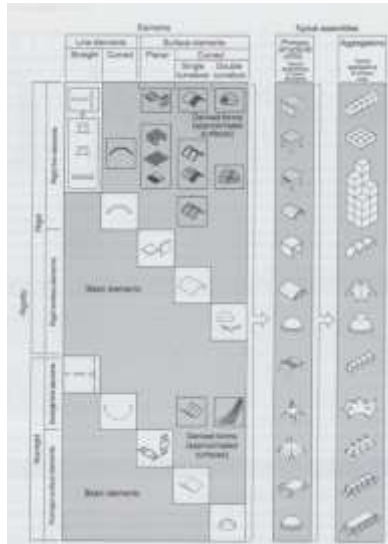
Arquitetos: Ictinus e Callicrates, sob a supervisão do escultor Phidias.  
Início da construção 447 AC



## Museu do Amanhã

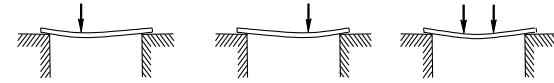
Santiago Calatrava, Rio de Janeiro, 2016



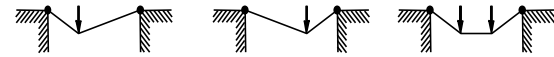


Classification of basic structural elements according to geometry and physical characteristics.  
Daniel Shodek, 'Structures', 1992

### Sistemas Rígidos x Sistemas Flexíveis:

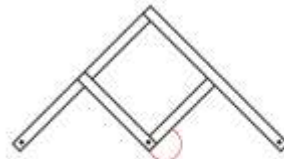


(a) Um sistema rígido, como uma viga, não muda drasticamente sua forma quando o carregamento varia



(b) Um Sistema 'flexível, como um cabo, pode mudar drasticamente de forma, quando carregamento varia

### Pantógrafos



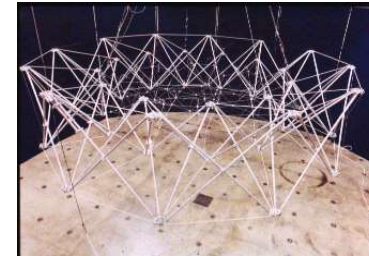
### Pantógrafos são mecanismos, que podem ser empregados como estruturas:



### *Estruturas Pantográficas*



### *Estruturas Pantográficas*



### *Treliças Planas*



### *Pórtico Treliçado: Sainsbury Centre for Visual Arts (Norman Foster, 1974) East Anglia University, Norwich, Inglaterra*



**Sainsbury Centre for Visual Arts (Norman Foster, 1974)**  
*East Anglia University, Norwich, Inglaterra*



**Sainsbury Centre for Visual Arts (Norman Foster, 1974)**  
*East Anglia University, Norwich, Inglaterra*

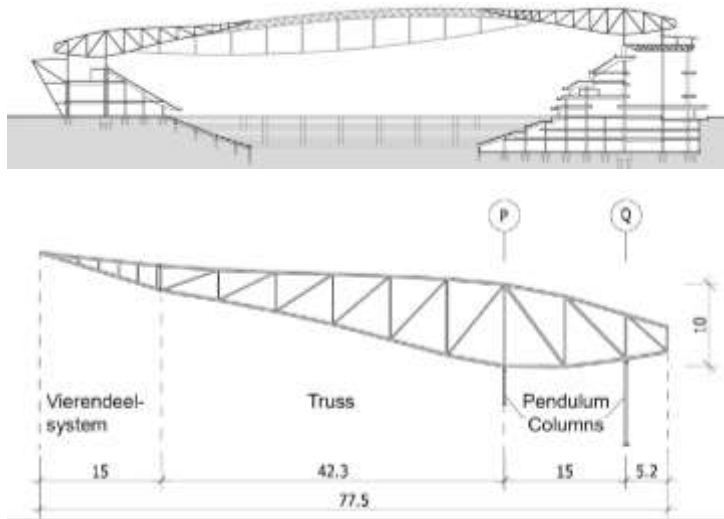


**Pórtico treliçado e estaiado:**  
*Escola Panamericana de Arte, Ziegbert Zanettini, 1999*



**Treliças, pórticos, cabos e sistema Vierendeel:**  
*Arena Corinthians, Arq. Anibal Coutinho, 2016*  
*Cobertura: Werner Sobek*





*Membranas, cabos, e arcos treliçados no 'Morro da Urca', Rio de Janeiro, 2014*



(1) Nelson Fielder

(2) Pedro Marcelo Paim de Santana





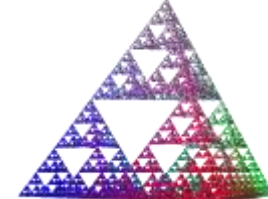
R.M.O.Pauletti - [www.lmc.ep.usp.br/people/pauletti/](http://www.lmc.ep.usp.br/people/pauletti/)



## *Treliças Planas x Treliças Espaciais*



*Triângulo de Sierpinski*



*Pirâmide de Sierpinski*



## *Treliças Planas x Treliças Espaciais*



## *Treliças Espaciais*



*Catedral de Cristal, Arq. Johnson Burgee, Garden Grove, California, EUA, 1978-80*



### Exemplos: Treliças Espaciais



### Alexander Graham Bell and the Octet Truss

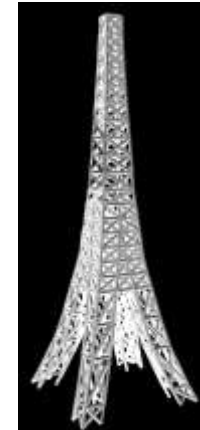
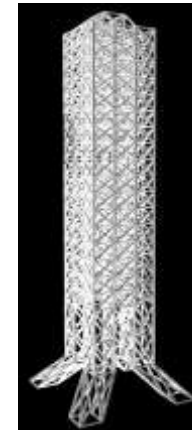


"Climaxing Bell's architectural experiments with tetrahedral structures was an observation tower at Beinn Bhreagh, his summer estate near Baddeck, Nova Scotia. Each unit for this tower consisted of six 4-foot pieces of ordinary galvanized iron pipe and four connecting nuts; the units, themselves, were riveted together in the field by unskilled labor. Upon its completion in September 1907, the tower stood nearly 80 feet high."

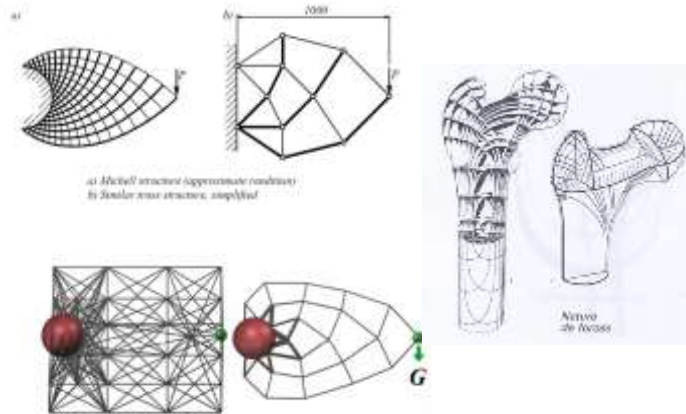




Torre Eiffel - uma estrutura otimizada



Michell's Truss (~1900)



'Radiolara' - gridshells na natureza



Árvores:  
Aeroporto de Stuttgart,  
Architect: Gerkan, Mag. and Partners, Hamburg (1981-1991, planejamento / construção).



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Aeroporto de Stuttgart,  
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Sibelius Hall  
Finlândia



Sibelius Hall  
Finlândia, 2000.



Architects Kimmo Lintula and Hannu Tikka.



## Domos Geodésicas

Pavilhão norte-americano da EXPO 1967 (Montreal)  
R. Buckminster Fuller.



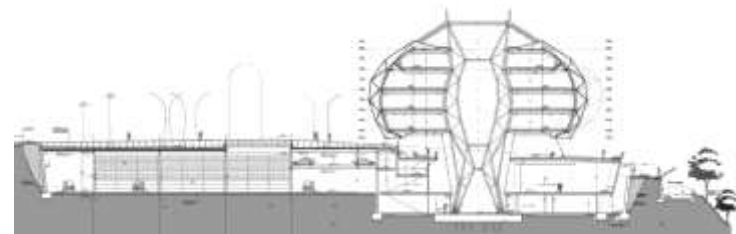
## Domo Geodésico – iGuzzini (Josep Miás, 2011)



## iGuzzini (Josep Miás, 2011)

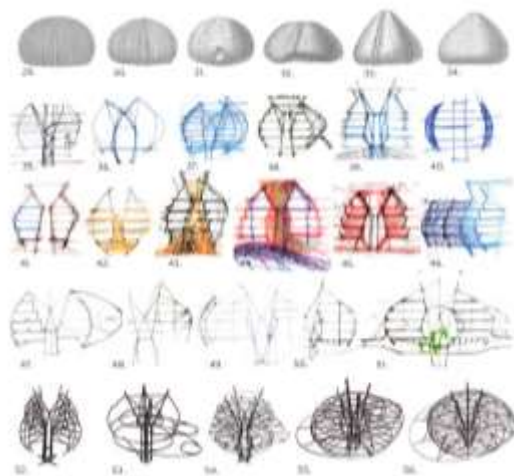


## iGuzzini (Josep Miás, 2011)



Edifício sede da iguzzini illuminazione ibérica s.a.  
Barcelona, 2006 (concurso) 2008-2011 (construção)  
Arquiteto: Josep Miàs  
Área: 9,000 m<sup>2</sup>  
Orçamento: 12m €



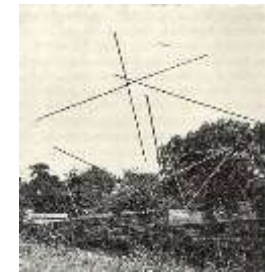


39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.

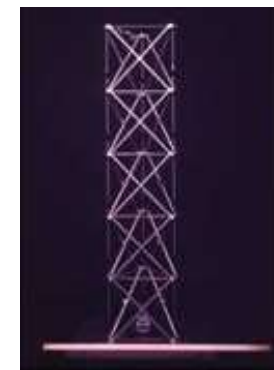
## Estruturas 'tensegrity'

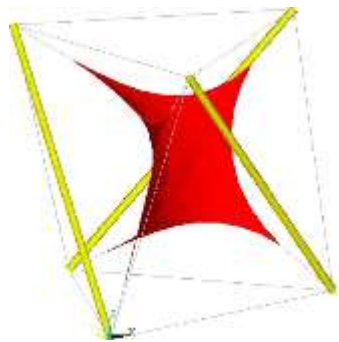


"Needle Tower",  
Kenneth Snelson, 1948

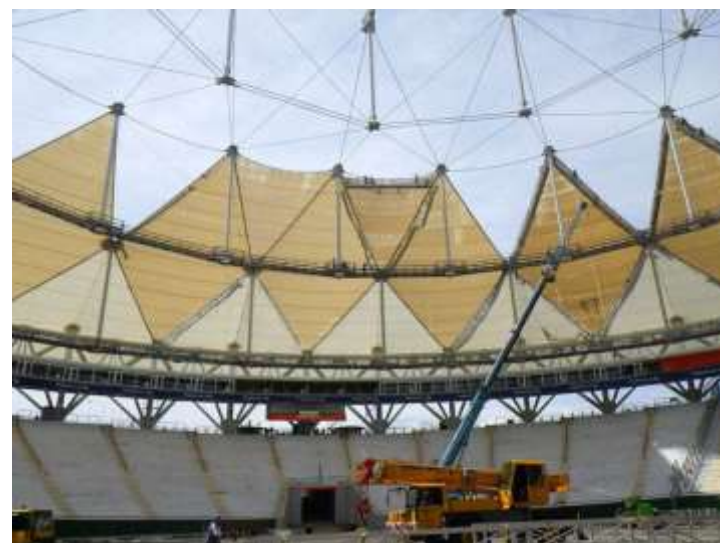


Monument à la Forme Futile  
Emmerich, 1966





*Estadio Único Ciudad de La Plata*  
*Roberto Ferreira & Arquitectos Asociados*  
*Conclusão: 2011*



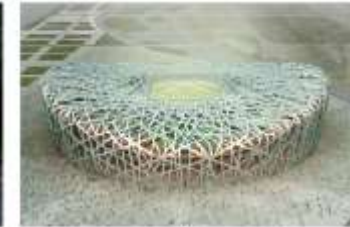
Estádio Olímpico de Pequim  
 "Bird's Nest"  
 Março, 2008



Location: Beijing, China  
 Broke ground: December 2003  
 Owner: Government of the People's Republic of China  
 Construction cost: ~USD \$500 million  
 Architect: Herzog & de Meuron, ArupSport, CAG  
 Capacity: 80,000 / 91,000 (Olympics)



(a)



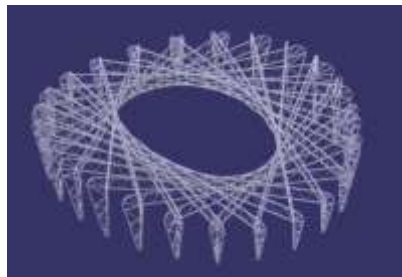
(b)

Figure 1. Basket-like structures. (a) The "5-dimensional quasi-periodic" garden pavilion by Olafur Eliasson in Holbæk, Denmark, 1998 (courtesy of Mr Eliasson). (b) The Beijing Olympic Stadium designed by Herzog & de Meuron for the 2008 Olympic Games (taken from the Internet).



BASKETS

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 Professor, Department of Structural Mechanics, Technical University of Berlin  
 Augusten, Augusten-Str. 2, D-10585 Berlin



RESEARCH & DESIGN OF TWISTED BOX SECTIONS OF PRIMARY  
 STRUCTURES FOR NATIONAL STADIUM BEIJING

Design: FADP, V. P. P. 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 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