Comparing stochastic search algorithms for computational protein design

David Mignon and Thomas Simonson*

†Laboratoire de Biochimie (UMR CNRS 7654), Dept. of Biology, Ecole Polytechnique, Palaiseau, France *Corresponding author. Email: thomas.simonson@polytechnique.fr

Table 1: Selected MC and REMC protocols

name	walker temperature(s) kT (kcal/mol)	trajectory length (steps)	move probabilities[a] rot;mut;mut+rot; mut+mut;	walker swap periodicity[b]
MC	0.2	$6\ 10^9$	0; 1; 0.1; 0	-
REMCa	0.125; 0.25; 0.5; 1	$1.5\ 10^9$	1; 0; 0.1; 0	$7.5\ 10^6$
REMCb	0.25; 0.5; 1; 2	$1.5\ 10^9$	1; 0; 0.1; 0	$7.5\ 10^6$
REMCc	0.175; 0.263; 0.395; 0.592; 0.888; 1.333; 2; 3	$0.75\ 10^9$	0; 1; 0.1; 0	$7.5\ 10^6$
REMCd	0.175; 0.263; 0.395; 0.592; 0.888; 1.333; 2; 3	$0.75\ 10^9$	1; 0; 0.1; 0	$7.5\ 10^6$
REMCe	0.175; 0.263; 0.395; 0.592; 0.888; 1.333; 2;	$0.75\ 10^9$	1; 0; 0.1; 0	10^6

[a]Probabilities at each MC step to change, respectively, a rotamer; a sidechain type; a type at one position and a rotamer at another; a type at two positions. [b]The interval between attempts to exchange states between two walkers (using a Metropolis test).

Table 2: Test proteins

type	PDB	length	acronym	type	PDB	length	acronym
PDZ	1G9O	91	NHERF	SH2	1A81	108	Syk kinase
PDZ	1R6J	82	syntenin	SH2	1BM2	98	Grb2
PDZ	2BYG	97	DLH2	SH2	1M61	109	Zap70
SH3	1ABO	58	Abl	SH2	1O4C	104	Src kinase
SH3	1CKA	57	c-Crk				

Table 3: Designed sequence quality measures

Protein	Number of sequences tested	Identity % to wildtype	Superfamily tests				
			Match length	Superfamily E-value	Superfamily success rate	Family E-value	Family success rate
1A81	236	27	none				
1ABO	203	32	51/58	4.4e-4	100%	2.8e-3	100%
1BM2	209	27	78/98	4.2e-5	100%	2.6e-3	100%
1CKA	416	33	40/57	1.1e-5	100%	3.4e-3	100%
1G9O	338	36	79/91	7.0e-7	100%	2.5e-3	100%
1M61	405	42	97/109	7.2e-7	100%	2.6e-4	100%
1O4C	274	21	95/104	2.1e-4	100%	4.5e-3	100%
1R6J	270	34	74/82	9.8e-6	100%	4.6e-3	100%
2BYG	426	28	59/97	1.4e-5	100%	7.1e-3	100%

Table 4: Tests with 10 designed positions

rotamers[a]	length[b]	Protein	CFN[c]	Heur.[d]	MC	REMC
2991	108(17)	1A81 3	gmec	0.001	0.1595	
		1A81 4	gmec	0.	0.0317	
		1A81 5	gmec	0.	0.0563	
2520	58(8)	1ABO 1	gmec	0.0675	0.9054	0.8041
		1ABO 4	gmec	0.	0.0128	
2957	98(10)	1BM2 1	gmec	0.	0.0950	
		1BM2 5	gmec	0.	0.1082	
2508	57(8)	1CKA 5	gmec	0.2859	3.2525	0.
2819	91(15)	1G9O 3	gmec	0.1366	0.1366	
		1G9O 5	gmec	0.	3.9599	0.
2957	109(21)	1M61 1	gmec	0.	0.0776	
		1M61 2	gmec	3.5105	4.5062	0.3215
		1M61 5	gmec	0.	0.0432	
3037	104(8)	1O4C 1	gmec	0.	0.1121	
		1O4C 2	gmec	0.	0.1046	
		1O4C 3	gmec	0.	0.1519	
		1O4C 4	gmec	0.	0.1545	
		1O4C 5	gmec	0.	0.1753	
2773	82(10)	1R6J 1	gmec	0.	2.4022	0.3986
		1R6J 2	gmec	0.	1.0398	0.3049
		1R6J 3	gmec	0.	0.0106	
		1R6J 5	gmec	0.	0.0162	
2888	97(15)	2BYG 1	5.7485	0.	0.0337	
		2BYG 3	gmec	0.	0.0833	
		2BYG 4	gmec	0.	0.2149	

[a]Total number of rotamers available to the system. Each designed position can explore 206 rotamers; the others explore about 10 rotamers each. [b]Total protein length (number of Gly+Pro in parentheses). [c]gmec indicates the GMEC was successfully identified. [d]For all four exploration methods and each test, we report the difference between the best energy obtained and the overall best energy (the best over all methods, which may or not be the GMEC). 10-position tests where all four methods found the GMEC are not listed.

Table 5: Tests with 20 and 30 designed positions

	20 positions					30 positions			
Protein	CFN	Heur.	MC	REMC	mutations[a]	CFN	Heur.	MC	REMC
1A81 1	gmec*	0.	0.3275	0.3851	0	1.2074	0.	0.6353	
1A81 2	gmec*	0.1705	2.4355	1.0069	3	2.5520	0.	0.0578	
1A81 3	gmec	0.	0.4640	0.6186	0	43.5263	0.	2.4996	1.2025
1A81 4	gmec	0.3878	0.5748	0.6991	4	5.1300	0.	0.0305	
1A81 5	gmec	0.0068	0.5088	0.1541	4	3.2417	0.	1.9586	0.5791
1ABO 1	gmec	0.1205	1.1159	0.2153	2	44.5504	0.	0.	
1ABO 2	13.8563	0.	0.	0.	8	12.7303	0.	0.	
1ABO 3	1.2190	0.	0.	0.	9	9.3870	0.	0.2630	
1ABO 4	1.9940	0.	0.0076	0.	5	10.7691	0.	0.	
1ABO 5	3.5418	0.	0.9483	0.9483	9	4.3907	0.	0.	
1BM2 1	gmec	0.	0.0619	0.1584	0	22.5876	0.	1.7290	1.6013
1BM2 2	7.5304	0.	0.0725	0.0143	8	22.1386	0.	1.9856	1.5876
1BM2 3	gmec	0.0229	0.4762	0.2897	0	22.5410	0.	1.9990	1.1541
1BM2 4	0.1186	0.	2.5883	0.0789	2	15.2639	0.	2.2127	2.3854
1BM2 5	gmec	0.2396	0.3746	0.3746	3	15.9890	0.	2.8354	1.1937
1CKA 1	gmec*	0.	0.	0.	0	6.2700	0.	0.	
1CKA 2	gmec	0.	0.	0.	0	2.0995	0.	0.	
1CKA 3	gmec	0.	0.	0.	0	47.0217	0.	0.	
1CKA 4	4.3122	0.	0.	0.	4	44.0830	0.	0.	
1CKA 5	4.2849	0.	0.	0.	3	8.8608	0.	0.	
1G9O 1	2.0574	0.	1.2525	1.2525	5	2.0816	0.	1.5942	0.
1G9O 2	3.2106	0.	0.2177	0.1915	1	0.3270	0.	0.3126	
1G9O 3	1.9008	0.	0.4417	0.1019	1	17.7150	0.	1.5667	1.5667
1G9O 4	0.5030	0.	0.3855	0.1455	5	2.9758	0.	1.4284	1.6202
1G9O 5	0.4298	0.	0.1495	0.5114	5	0.	1.6890	7.6985	2.3857
1M61 1	gmec	0.	0.	0.	0	14.4935	0.0097	0.	0.
1M61 2	gmec	0.	0.	0.	0	5.0899	0.	1.8749	0.008
1M61 3	gmec	0.	0.	0.	0	3.5795	0.	0.0154	
1M61 4	gmec	0.	0.	0.	0	16.1511	0.	0.	
1M61 5	gmec	0.	0.2521	0.1345	0	23.0927	0.	0.	
1O4C 1	0.	0.3465	0.0690	0.0587	6	14.9064	0.	0.3435	
1O4C 2	6.4214	0.	0.1963	0.3175	4	58.1558	0.	0.0795	
1O4C 3	gmec	0.	0.3461	0.0997	0	9.9221	0.	0.1789	
1O4C 4	gmec	0.	0.3640	0.1382	0	5.7790	0.	0.0423	
1O4C 5	0.	0.	0.1131	0.2206	0	9.9221	0.	0.1789	
1R6J 1	gmec	0.	0.2604	0.2002	0	gmec*	0.	0.0246	
1R6J 2	gmec	0.	0.0071	0.0183	0	14.9800	0.	0.0957	
1R6J 3	gmec	0.	0.0537	0.0732	0	0.	0.	0.0440	
1R6J 4	gmec	0.	0.0639	0.0601	0	0.	0.	0.0957	
1R6J 5	gmec	0.	0.0735	0.0244	0	0.	0.7036	1.8823	0.0781
2BYG 1	gmec	0.	3.1878	0.0257	0	17.9752	0.	0.1592	
2BYG 2	gmec	0.	0.0524	0.0831	0	0.3832	0.	0.1502	
2BYG 3	gmec*	0.	1.3564	0.0826	0	0.1442	0.	0.1593	
2BYG 4	gmec	0.	0.1968	0.6022	0	0.	0.0958	0.0050	
2BYG 5	1.8604	0.	0.0933	0.0386	2	0.5003	0.	0.6876	

Format as in Table 4. gmec* indicates the more aggressive protocol. [a]Between CFN/Heur.

Table 6: Designed and Pfam sequence entropies

Protein	Top 10,000 structures	Top 10,000 sequences	Pfam seed	Pfam full
1ABO	1.36	1.58	2.79	3.01
1CKA	1.20	1.41	2.84	3.03
1R6J	1.33	1.48	3.11	3.66
1G9O	1.21	1.53	3.29	3.81
2BYG	1.57	1.63	3.31	3.67
1BM2	1.08	1.26	2.90	3.50
1O4C	1.36	1.68	2.94	3.47
1M61	1.31	1.41	2.91	3.51
1A81	1.13	1.29	2.91	3.51

The entropies are exponentiated, then averaged over all positions. The designed entropies correspond to REMC runs where all positions are designed (except Gly/Pro).