HW2 Tao Chen

The CPU information I used is:

```
Architecture:            x86_64
CPU op-mode(s):          32-bit, 64-bit
Byte Order:              Little Endian
CPU(s):                  64
On-line CPU(s) list:     0-63
Thread(s) per core:      2
Core(s) per socket:      8
Socket(s):               4
NUMA node(s):            8
Vendor ID:               AuthenticAMD
CPU family:              21
Model:                   2
Model name:              AMD Opteron(tm) Processor 6380
Stepping:                0
CPU MHz:                 2499.940
BogoMIPS:                4999.88
Virtualization:          AMD-V
L1d cache:               16K
L1i cache:               64K
L2 cache:                2048K
L3 cache:                6144K
NUMA node0 CPU(s):       0-7
NUMA node1 CPU(s):       8-15
NUMA node2 CPU(s):       32-39
NUMA node3 CPU(s):       40-47
NUMA node4 CPU(s):       48-55
NUMA node5 CPU(s):       56-63
NUMA node6 CPU(s):       16-23
NUMA node7 CPU(s):       24-31
```

Problem 1:

1. x should be freed instead of deleted; exceeding array bound when visiting elements of x.

2. Not every elements of X is initialized.

Problem 2:

(1) optimal order:

jpi:

Dimension	Time	Gflop/s	GB/s	Error
24	0.634715	3.151022	26.258515	0.000000e+00
72	0.483213	4.140222	33.581797	0.000000e+00
120	0.459675	4.353125	35.115207	0.000000e+00
168	0.448987	4.456634	35.865294	0.000000e+00
216	0.499628	4.034083	32.422078	0.000000e+00
264	0.488156	4.146160	33.294925	0.000000e+00
312	0.476841	4.203723	33.737575	0.000000e+00
360	0.480784	4.269822	34.253457	0.000000e+00
408	0.496153	4.106637	32.933618	0.000000e+00
456	0.572947	3.640851	29.190680	0.000000e+00
504	0.772899	2.650263	21.244168	0.000000e+00
552	0.844628	2.389642	19.151767	0.000000e+00
600	0.943083	2.290361	18.353423	0.000000e+00
648	1.025593	2.122462	17.005903	0.000000e+00
696	0.956600	2.114699	16.941903	0.000000e+00
744	1.171357	2.109506	16.898730	0.000000e+00
792	1.428002	2.087364	16.719994	0.000000e+00
840	1.140318	2.079084	16.652474	0.000000e+00
888	1.354288	2.068178	16.564053	0.000000e+00
936	1.599741	2.050397	16.420699	0.000000e+00
984	1.917486	1.987527	15.916378	0.000000e+00

ijp:

Dimension	Time	Gflop/s	GB/s	Error
24	1.328797	1.505122	12.542684	0.000000e+00
72	1.552637	1.288523	10.451355	0.000000e+00
120	1.647640	1.214479	9.796797	0.000000e+00
168	1.689350	1.184460	9.532087	0.000000e+00
216	1.924865	1.047107	8.415638	0.000000e+00
264	1.939392	1.043612	8.380517	0.000000e+00
312	1.928875	1.039211	8.340333	0.000000e+00
360	2.022310	1.015108	8.143426	0.000000e+00
408	2.092240	0.973846	7.809864	0.000000e+00
456	2.328349	0.895920	7.183075	0.000000e+00
504	2.516135	0.814100	6.525720	0.000000e+00
552	2.616682	0.771343	6.181923	0.000000e+00
600	2.631370	0.820865	6.577866	0.000000e+00
648	2.662132	0.817684	6.551567	0.000000e+00
696	2.506746	0.806991	6.465202	0.000000e+00
744	3.095180	0.798333	6.395250	0.000000e+00
792	3.508645	0.849547	6.804957	0.000000e+00
840	2.836944	0.835694	6.693509	0.000000e+00
888	3.395002	0.825009	6.607508	0.000000e+00
936	3.827865	0.856902	6.862536	0.000000e+00
984	4.530627	0.841176	6.736248	0.000000e+00

ijp:

Dimension	Time	Gflop/s	GB/s	Error
24	1.323561	1.511076	12.592299	0.000000e+00
72	1.537833	1.300927	10.551966	0.000000e+00
120	1.641190	1.219252	9.835296	0.000000e+00
168	1.687963	1.185434	9.539921	0.000000e+00
216	1.943709	1.036955	8.334047	0.000000e+00
264	1.948447	1.038762	8.341570	0.000000e+00
312	1.933188	1.036892	8.321723	0.000000e+00
360	2.008557	1.022059	8.199185	0.000000e+00
408	2.108105	0.966517	7.751088	0.000000e+00
456	2.302928	0.905810	7.262368	0.000000e+00
504	2.438126	0.840147	6.734515	0.000000e+00
552	2.433024	0.829568	6.648569	0.000000e+00
600	2.581593	0.836693	6.704696	0.000000e+00
648	2.301598	0.945770	7.577837	0.000000e+00
696	2.178649	0.928521	7.438841	0.000000e+00
744	2.332094	1.059556	8.487845	0.000000e+00
792	2.938845	1.014262	8.124341	0.000000e+00
840	2.392094	0.991105	7.938278	0.000000e+00
888	2.834013	0.988319	7.915454	0.000000e+00
936	3.176474	1.032624	8.269817	0.000000e+00
984	3.817962	0.998191	7.993644	0.000000e+00

ipj:

Dimension	Time	Gflop/s	GB/s	Error
24	1.553191	1.287672	10.730603	0.000000e+00
72	2.293829	0.872170	7.074268	0.000000e+00
120	4.026546	0.496958	4.008794	0.000000e+00
168	4.641894	0.431067	3.469066	0.000000e+00
216	4.707981	0.428111	3.440745	0.000000e+00
264	4.694616	0.431126	3.462074	0.000000e+00
312	4.616503	0.434205	3.484772	0.000000e+00
360	4.705024	0.436313	3.500201	0.000000e+00
408	4.720968	0.431589	3.461177	0.000000e+00
456	5.139937	0.405844	3.253874	0.000000e+00
504	5.476057	0.374062	2.998434	0.000000e+00
552	5.148357	0.392040	3.141998	0.000000e+00
600	5.581944	0.386962	3.100855	0.000000e+00
648	5.753599	0.378334	3.031343	0.000000e+00
696	5.251480	0.385210	3.086106	0.000000e+00
744	6.407443	0.385643	3.089290	0.000000e+00
792	8.625583	0.345572	2.768065	0.000000e+00
840	6.111889	0.387902	3.106913	0.000000e+00
888	7.264185	0.385578	3.088096	0.000000e+00
936	8.454549	0.387969	3.107068	0.000000e+00
984	9.886654	0.385475	3.086932	0.000000e+00

pij:

Dimension	Time	Gflop/s	GB/s	Error
24	1.242160	1.610099	13.417491	0.000000e+00
72	2.492182	0.802754	6.511227	0.000000e+00
120	4.020594	0.497694	4.014729	0.000000e+00
168	4.647883	0.430512	3.464596	0.000000e+00
216	4.703366	0.428531	3.444122	0.000000e+00
264	4.700204	0.430614	3.457958	0.000000e+00
312	4.630520	0.432890	3.474223	0.000000e+00
360	4.732281	0.433800	3.480041	0.000000e+00
408	4.757640	0.428263	3.434498	0.000000e+00
456	5.041351	0.413781	3.317506	0.000000e+00
504	5.279256	0.388006	3.110210	0.000000e+00
552	5.514973	0.365978	2.933129	0.000000e+00
600	15.260754	0.141540	1.134203	0.000000e+00
648	5.915398	0.367986	2.948429	0.000000e+00
696	5.249596	0.385348	3.087213	0.000000e+00
744	6.543117	0.377646	3.025232	0.000000e+00
792	8.687641	0.343103	2.748292	0.000000e+00
840	6.133192	0.386555	3.096122	0.000000e+00
888	7.286716	0.384386	3.078547	0.000000e+00
936	10.161667	0.322792	2.585094	0.000000e+00
984	10.107668	0.377046	3.019433	0.000000e+00

pji:

Dimension	Time	Gflop/s	GB/s	Error
24	0.611002	3.273311	27.277595	0.000000e+00
72	0.601896	3.323845	26.960076	0.000000e+00
120	0.571569	3.500931	28.240842	0.000000e+00
168	0.573219	3.490757	28.092279	0.000000e+00
216	0.610069	3.303787	26.552655	0.000000e+00
264	0.599847	3.374147	27.095422	0.000000e+00
312	0.594473	3.371904	27.061692	0.000000e+00
360	0.603003	3.404400	27.310857	0.000000e+00
408	0.672393	3.030253	24.301438	0.000000e+00
456	0.731963	2.849891	22.849129	0.000000e+00
504	0.809557	2.530253	20.282185	0.000000e+00
552	0.961145	2.099954	16.830063	0.000000e+00
600	1.111730	1.942919	15.569254	0.000000e+00
648	1.074995	2.024924	16.224391	0.000000e+00
696	0.988629	2.046188	16.393023	0.000000e+00
744	1.217088	2.030244	16.263779	0.000000e+00
792	1.461388	2.039677	16.338017	0.000000e+00
840	1.178951	2.010953	16.106780	0.000000e+00
888	1.376121	2.035364	16.301251	0.000000e+00
936	1.639702	2.000427	16.020511	0.000000e+00
984	2.027856	1.879353	15.050100	0.000000e+00

From the above 6 orders, we can see that the most efficient order is "jpi" and "pji", that's because, under "jpi" and "pji", the inner most loop is column-wise iterations of A and C, and the data is stored column wise, so under this case it is the most efficient.

(ii) Blocking scheme under "jpi" order:
(with block size = 24)

Dimension	Time	Gflop/s	GB/s	Error
24	0.403922	4.951449	41.262073	0.000000e+00
72	0.434220	4.607368	37.370871	0.000000e+00
120	0.427332	4.682593	37.772918	0.000000e+00
168	0.438146	4.566898	36.752651	0.000000e+00
216	0.430559	4.681212	37.623071	0.000000e+00
264	0.432745	4.677052	37.558141	0.000000e+00
312	0.431582	4.644563	37.275597	0.000000e+00
360	0.442077	4.643682	37.252648	0.000000e+00
408	0.449663	4.531210	36.338525	0.000000e+00
456	0.472333	4.416403	35.408708	0.000000e+00
504	0.484033	4.231908	33.922435	0.000000e+00
552	0.472065	4.275594	34.266716	0.000000e+00
600	0.500275	4.317621	34.598539	0.000000e+00
648	0.499677	4.356377	34.904798	0.000000e+00
696	0.465294	4.347624	34.830963	0.000000e+00
744	0.570731	4.329511	34.682645	0.000000e+00
792	0.685272	4.349743	34.841885	0.000000e+00
840	0.546219	4.340416	34.764666	0.000000e+00
888	0.652836	4.290371	34.361622	0.000000e+00
936	0.766824	4.277520	34.256720	0.000000e+00
984	0.913340	4.172659	33.415194	0.000000e+00

we can see that with blocking, as the size of the matrix increases, flop and bandwidth won't decrease that much compared to the previous without blocking case.

(iii) Experiment with different values for block size.

Block size = 4

Dimension	Time	Gflop/s	GB/s	Error
4	0.443732	4.507222	45.072224	0.000000e+00
52	0.397666	5.029363	41.008648	0.000000e+00
100	0.383403	5.221654	42.190963	0.000000e+00
148	0.384858	5.205623	41.926373	0.000000e+00
196	0.396923	5.045956	40.573603	0.000000e+00
244	0.415712	4.822324	38.736701	0.000000e+00
292	0.449908	4.537733	36.426186	0.000000e+00
340	0.484133	4.221588	33.872033	0.000000e+00
388	0.497789	4.224277	33.881318	0.000000e+00
436	0.513777	4.194286	33.631247	0.000000e+00
484	0.491413	4.153003	33.292672	0.000000e+00
532	0.517706	4.071737	32.635122	0.000000e+00
580	0.583965	4.009392	32.130439	0.000000e+00
628	0.612282	4.045085	32.412214	0.000000e+00
676	0.612205	4.036762	32.341866	0.000000e+00
724	0.563232	4.042778	32.386899	0.000000e+00
772	0.685056	4.029741	32.279688	0.000000e+00
820	0.543655	4.056746	32.493547	0.000000e+00
868	0.646267	4.047690	32.418823	0.000000e+00
916	0.756807	4.062198	32.533062	0.000000e+00
964	0.889335	4.029265	32.267560	0.000000e+00

Block size = 8

Dimension	Time	Gflop/s	GB/s	Error
4	0.443732	4.507222	45.072224	0.000000e+00
52	0.397666	5.029363	41.008648	0.000000e+00
100	0.383403	5.221654	42.190963	0.000000e+00
148	0.384858	5.205623	41.926373	0.000000e+00
196	0.396923	5.045956	40.573603	0.000000e+00
244	0.415712	4.822324	38.736701	0.000000e+00
292	0.449908	4.537733	36.426186	0.000000e+00
340	0.484133	4.221588	33.872033	0.000000e+00
388	0.497789	4.224277	33.881318	0.000000e+00
436	0.513777	4.194286	33.631247	0.000000e+00
484	0.491413	4.153003	33.292672	0.000000e+00
532	0.517706	4.071737	32.635122	0.000000e+00
580	0.583965	4.009392	32.130439	0.000000e+00
628	0.612282	4.045085	32.412214	0.000000e+00
676	0.612205	4.036762	32.341866	0.000000e+00
724	0.563232	4.042778	32.386899	0.000000e+00
772	0.685056	4.029741	32.279688	0.000000e+00
820	0.543655	4.056746	32.493547	0.000000e+00
868	0.646267	4.047690	32.418823	0.000000e+00
916	0.756807	4.062198	32.533062	0.000000e+00
964	0.889335	4.029265	32.267560	0.000000e+00

Block size = 12

Dimension	Time	Gflop/s	GB/s	Error
12	0.569742	3.510363	30.423148	0.000000e+00
60	0.610644	3.275495	26.640691	0.000000e+00
108	0.600976	3.328622	26.875537	0.000000e+00
156	0.613467	3.267507	26.307617	0.000000e+00
204	0.619670	3.233271	25.992966	0.000000e+00
252	0.618898	3.258015	26.167551	0.000000e+00
300	0.625631	3.279886	26.326554	0.000000e+00
348	0.618722	3.269517	26.231296	0.000000e+00
396	0.642702	3.285147	26.347545	0.000000e+00
444	0.649363	3.234986	25.938179	0.000000e+00
492	0.691406	3.100523	24.854596	0.000000e+00
540	0.721796	3.054182	24.478702	0.000000e+00
588	0.671010	3.029724	24.279014	0.000000e+00
636	0.679690	3.027962	24.261783	0.000000e+00
684	0.884803	2.893420	23.181203	0.000000e+00
732	0.785102	2.997494	24.012713	0.000000e+00
780	0.952029	2.990781	23.956926	0.000000e+00
828	0.759837	2.988344	23.935622	0.000000e+00
876	0.903488	2.976117	23.836116	0.000000e+00
924	1.077283	2.929180	23.458802	0.000000e+00
972	1.294709	2.837178	22.720771	0.000000e+00

Block size = 16

Dimension	Time	Gflop/s	GB/s	Error
16	1.275399	1.568139	13.329185	0.000000e+00
64	1.313758	1.522471	12.370076	0.000000e+00
112	1.321136	1.514316	12.222695	0.000000e+00
160	1.312619	1.529035	12.308730	0.000000e+00
208	1.333060	1.512127	12.155178	0.000000e+00
256	1.567844	1.284099	10.312917	0.000000e+00
304	1.333711	1.516671	12.173282	0.000000e+00
352	1.348424	1.487851	11.936621	0.000000e+00
400	1.370809	1.494009	11.981949	0.000000e+00
448	1.483636	1.454514	11.662088	0.000000e+00
496	1.498362	1.465888	11.750745	0.000000e+00
544	1.541501	1.462113	11.718404	0.000000e+00
592	1.439233	1.441565	11.551997	0.000000e+00
640	1.627298	1.288733	10.325969	0.000000e+00
688	1.789374	1.455976	11.664740	0.000000e+00
736	1.643959	1.455103	11.656641	0.000000e+00
784	1.990444	1.452611	11.635714	0.000000e+00
832	1.617547	1.424207	11.407347	0.000000e+00
880	1.889321	1.442787	11.555416	0.000000e+00
928	2.215979	1.442575	11.553034	0.000000e+00
976	2.574567	1.444459	11.567513	0.000000e+00

Block size = 20

Dimension	Time	Gflop/s	GB/s	Error
20	0.988879	2.022509	16.989074	0.000000e+00
60	1.001491	1.997182	16.243744	0.000000e+00
100	1.003958	1.994107	16.112382	0.000000e+00
140	0.969952	2.065174	16.639399	0.000000e+00
180	0.941928	2.129896	17.133831	0.000000e+00
220	1.008620	1.984716	15.949898	0.000000e+00
260	0.970540	2.064484	16.579393	0.000000e+00
300	1.017040	2.017619	16.194756	0.000000e+00
340	0.984034	2.076969	16.664625	0.000000e+00
380	1.033180	2.018173	16.187874	0.000000e+00
420	1.025410	2.023059	16.223003	0.000000e+00
460	1.040852	2.057346	16.494545	0.000000e+00
500	1.111827	2.023696	16.221946	0.000000e+00
540	1.097000	2.009567	16.106310	0.000000e+00
580	1.184953	1.975896	15.834420	0.000000e+00
620	1.191977	1.999435	16.021279	0.000000e+00
660	1.120359	2.052885	16.447960	0.000000e+00
700	1.014287	2.029011	16.255280	0.000000e+00
740	1.200390	2.025462	16.225593	0.000000e+00
780	1.399758	2.034146	16.294032	0.000000e+00
820	1.135546	1.942213	15.556653	0.000000e+00
860	1.271937	2.000275	16.020809	0.000000e+00

Block size = 24

Dimension	Time	Gflop/s	GB/s	Error
24	0.403922	4.951449	41.262073	0.000000e+00
72	0.434220	4.607368	37.370871	0.000000e+00
120	0.427332	4.682593	37.772918	0.000000e+00
168	0.438146	4.566898	36.752651	0.000000e+00
216	0.430559	4.681212	37.623071	0.000000e+00
264	0.432745	4.677052	37.558141	0.000000e+00
312	0.431582	4.644563	37.275597	0.000000e+00
360	0.442077	4.643682	37.252648	0.000000e+00
408	0.449663	4.531210	36.338525	0.000000e+00
456	0.472333	4.416403	35.408708	0.000000e+00
504	0.484033	4.231908	33.922435	0.000000e+00
552	0.472065	4.275594	34.266716	0.000000e+00
600	0.500275	4.317621	34.598539	0.000000e+00
648	0.499677	4.356377	34.904798	0.000000e+00
696	0.465294	4.347624	34.830963	0.000000e+00
744	0.570731	4.329511	34.682645	0.000000e+00
792	0.685272	4.349743	34.841885	0.000000e+00
840	0.546219	4.340416	34.764666	0.000000e+00
888	0.652836	4.290371	34.361622	0.000000e+00
936	0.766824	4.277520	34.256720	0.000000e+00
984	0.913340	4.172659	33.415194	0.000000e+00

Block size = 28

Dimension	Time	Gflop/s	GB/s	Error
28	0.400429	4.994651	41.384252	0.000000e+00
56	0.422823	4.730741	38.521750	0.000000e+00
84	0.446476	4.481696	36.280396	0.000000e+00
112	0.412862	4.845731	39.111969	0.000000e+00
140	0.428100	4.679091	37.700106	0.000000e+00
168	0.462181	4.329402	34.841375	0.000000e+00
196	0.422498	4.740515	38.117611	0.000000e+00
224	0.427434	4.680528	37.611387	0.000000e+00
252	0.466516	4.322211	34.714904	0.000000e+00
280	0.430145	4.695127	37.695165	0.000000e+00
308	0.526600	3.883912	31.172176	0.000000e+00
336	0.433849	4.721423	37.883800	0.000000e+00
364	0.433343	4.674359	37.497603	0.000000e+00
392	0.442498	4.628348	37.121243	0.000000e+00
420	0.455438	4.554876	36.525771	0.000000e+00
448	0.523285	4.123887	33.064737	0.000000e+00
476	0.481475	4.479994	35.915246	0.000000e+00
504	0.490529	4.175868	33.473225	0.000000e+00
532	0.483636	4.358574	34.934137	0.000000e+00
560	0.471475	4.469790	35.822173	0.000000e+00
588	0.466210	4.360639	34.944441	0.000000e+00
616	0.559350	4.178869	33.485226	0.000000e+00

Block size = 32

Dimension	Time	Gflop/s	GB/s	Error
32	0.529963	3.773903	31.134696	0.000000e+00
64	0.561290	3.563504	28.953474	0.000000e+00
96	0.537866	3.720762	30.076159	0.000000e+00
128	0.694161	2.882160	23.237412	0.000000e+00
160	0.540266	3.714912	29.905041	0.000000e+00
192	0.579923	3.466182	27.873883	0.000000e+00
224	0.540709	3.699988	29.732043	0.000000e+00
256	0.688011	2.926214	23.501155	0.000000e+00
288	0.543434	3.692412	29.641863	0.000000e+00
320	0.583714	3.480499	27.931002	0.000000e+00
352	0.547562	3.663974	29.395064	0.000000e+00
384	0.668857	3.047635	24.444573	0.000000e+00
416	0.557730	3.614214	28.983217	0.000000e+00
448	0.626428	3.444879	27.620544	0.000000e+00
480	0.617207	3.583630	28.728766	0.000000e+00
512	0.766717	2.800882	22.450820	0.000000e+00
544	0.631070	3.571472	28.624297	0.000000e+00
576	0.668302	3.431435	27.499140	0.000000e+00
608	0.627330	3.582736	28.709025	0.000000e+00
640	0.699033	3.000078	24.038121	0.000000e+00
672	0.675384	3.594571	28.799359	0.000000e+00
704	0.610793	3.427480	27.458788	0.000000e+00

We can see that the optimal block size is 24 or ~~28~~.

(iv) Implementing openmp. (set number of threads = 8, block size = 24)

Without omp for

Dimension	Time	Gflop/s	GB/s	Error
24	0.400901	4.988765	41.573043	0.000000e+00
72	0.435086	4.598192	37.296447	0.000000e+00
120	0.424751	4.711050	38.002473	0.000000e+00
168	0.436187	4.587413	36.917755	0.000000e+00
216	0.431582	4.670120	37.533924	0.000000e+00
264	0.431330	4.692398	37.681376	0.000000e+00
312	0.433158	4.627658	37.139919	0.000000e+00
360	0.442907	4.634979	37.182834	0.000000e+00
408	0.454860	4.479443	35.923375	0.000000e+00
456	0.471901	4.420449	35.441147	0.000000e+00
504	0.483028	4.240720	33.993070	0.000000e+00
552	0.461748	4.371126	35.032361	0.000000e+00
600	0.499930	4.320603	34.622433	0.000000e+00
648	0.504098	4.318170	34.598670	0.000000e+00
696	0.465944	4.341555	34.782346	0.000000e+00
744	0.567700	4.352626	34.867810	0.000000e+00
792	0.691479	4.310701	34.529153	0.000000e+00
840	0.546936	4.334720	34.719042	0.000000e+00
888	0.650916	4.303025	34.462965	0.000000e+00
936	0.774787	4.233555	33.904627	0.000000e+00
984	0.923411	4.127148	33.050742	0.000000e+00

With omp for collapse(3)

Dimension	Time	Gflop/s	GB/s	Error
24	1.094056	1.828062	15.233848	0.000000e+00
72	0.386443	5.176980	41.991061	1.403188e+04
120	0.120859	16.556718	133.557523	5.820613e+02
168	0.080374	24.895654	200.350738	9.342574e+01
216	0.069709	28.913409	232.378143	1.546141e-11
264	0.069011	29.328438	235.516244	1.182343e-11
312	0.065447	30.628053	245.809761	9.549694e-12
360	0.065117	31.525765	252.906689	8.640200e-12
408	0.064930	31.380225	251.657099	4.774847e-12
456	0.067292	30.999593	248.540597	5.456968e-12
504	0.068529	29.890788	239.600763	5.911716e-12
552	0.067368	29.960042	240.114537	3.183231e-12
600	0.071861	30.058056	240.865224	3.410605e-12
648	0.074573	29.190067	233.880903	3.524292e-12
696	0.068014	29.742804	238.284307	3.183231e-12
744	0.083028	29.760682	238.405464	3.637979e-12
792	0.104082	28.638676	229.398685	4.433787e-12
840	0.081026	29.260051	234.359073	1.705303e-12
888	0.097926	28.602259	229.075749	1.875833e-12
936	0.118295	27.728159	222.062265	1.705303e-12
984	0.148534	25.657850	205.471404	1.932676e-12

With omp, the peak flop rate increases by 580%

(V) Without omp, using -O2 and -O3 respectively.
(block size = 24)

-O3

Dimension	Time	Gflop/s	GB/s	Error
24	0.400901	4.988765	41.573043	0.000000e+00
72	0.435086	4.598192	37.296447	0.000000e+00
120	0.424751	4.711050	38.002473	0.000000e+00
168	0.436187	4.587413	36.917755	0.000000e+00
216	0.431582	4.670120	37.533924	0.000000e+00
264	0.431330	4.692398	37.681376	0.000000e+00
312	0.433158	4.627658	37.139919	0.000000e+00
360	0.442907	4.634979	37.182834	0.000000e+00
408	0.454860	4.479443	35.923375	0.000000e+00
456	0.471901	4.420449	35.441147	0.000000e+00
504	0.483028	4.240720	33.993070	0.000000e+00
552	0.461748	4.371126	35.032361	0.000000e+00
600	0.499930	4.320603	34.622433	0.000000e+00
648	0.504098	4.318170	34.598670	0.000000e+00
696	0.465944	4.341555	34.782346	0.000000e+00
744	0.567700	4.352626	34.867810	0.000000e+00
792	0.691479	4.310701	34.529153	0.000000e+00
840	0.546936	4.334720	34.719042	0.000000e+00
888	0.650916	4.303025	34.462965	0.000000e+00
936	0.774787	4.233555	33.904627	0.000000e+00
984	0.923411	4.127148	33.050742	0.000000e+00

-O2

Dimension	Time	Gflop/s	GB/s	Error
24	1.630712	1.226459	10.220489	0.000000e+00
72	1.640428	1.219565	9.892028	0.000000e+00
120	1.710477	1.169863	9.436894	0.000000e+00
168	1.677906	1.192539	9.597101	0.000000e+00
216	1.678814	1.200573	9.649052	0.000000e+00
264	1.652624	1.224702	9.834726	0.000000e+00
312	1.639021	1.222991	9.815283	0.000000e+00
360	1.731750	1.185428	9.509765	0.000000e+00
408	1.692924	1.203550	9.652001	0.000000e+00
456	1.783226	1.169798	9.378904	0.000000e+00
504	1.752592	1.168775	9.368749	0.000000e+00
552	1.679987	1.201414	9.628721	0.000000e+00
600	1.833338	1.178179	9.441137	0.000000e+00
648	1.799218	1.209849	9.693728	0.000000e+00
696	1.679199	1.204694	9.651399	0.000000e+00
744	2.077281	1.189528	9.529017	0.000000e+00
792	2.493506	1.195409	9.575344	0.000000e+00
840	1.972866	1.201712	9.625137	0.000000e+00
888	2.329389	1.202422	9.630208	0.000000e+00
936	2.746209	1.194412	9.565501	0.000000e+00
984	3.347292	1.138549	9.117648	0.000000e+00

In general, -O3 is better than -O2.

Problem 3.

2. Add "reduction (+: total)" after pragma for

3. Delete the last "// pragma omp barrier"

4. define N to be smaller

5. In the second section,
   First lock a then lock b;
   First unlock b then unlock a.

6. define 'sum' in the outer most scope.

Problem 4.

jacobi:

# threads \ time \ N	10	50	100	200
4	0.010	0.372	0.989	3.504
8	0.013	0.351	0.727	2.383
16	0.019	0.404	0.692	1.856

G-S:

# threads \ time \ N	10	50	100	200
4	0.007	0.324	0.996	3.354
8	0.009	0.321	0.813	2.338
16	0.014	0.439	0.917	2.031

(Note: I set max_iterations = 5000 and break the iteration when error < 1e-6. So only when N=10, the error can be reduced to 1e-6 within 5000 iterations; for N=50, 100, and 200, it implements 5000 iterations).