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| МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ РОССИЙСКОЙ ФЕДЕРАЦИИ | |
| Федеральное государственное бюджетное образовательное учреждение высшего образования  «Пермский государственный национальный исследовательский университет» | |
| **ЧИСЛЕННЫЕ МЕТОДЫ** *Лабораторная работа №\_3\_*  **«**Прямые методы решения систем линейных алгебраических уравнений**»** | |
| Варианты: №3, №6 | |
|  | Работу выполнили студенты группы ПМИ-2-16  Мироненко Анастасия Олеговна,  Зимин Илья Владимирович |
| Оценка отчета   |  |  |  | | --- | --- | --- | |  | Баллы |  | | Конспект | 1 |  | | Опоздание с отчетом | -0.05 день |  | | Попытки | -0.5 попыт. |  | | Замечания к отчету | -0.25 зам. |  | | Программа | 1 |  | | Выводы  (Заключение) | 1 |  | | Защита | 1 |  | | ИТОГО: |  |  | | Проверил:  профессор, доктор физико-математических наук  С. В. Русаков  “\_\_\_\_” 2018 г. |
| Замечания:  Пермь 2018 | |

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1. **Задание**
2. Решить систему линейных алгебраических уравнений  итерационными методами с критерием остановки  (по невязке):

* методом простой итерации;
* градиентным методом наискорейшего спуска;
* методом ПВР;
* методом сопряженных градиентов.

В качества начального приближения выбирать вектор .

1. Для каждого метода получить число итераций, необходимое для достижения требуемой точности (по невязке), выдавая (на печать) на каждом шаге (или через заданное число шагов)

- значение параметров итерационного метода;

- значение нормы невязки;

- оценку нормы матрицы перехода *q*;

- оценку погрешности приближенного решения.

1. Оценку нормы матрицы перехода осуществлять по формуле



1. В методе простой итерации значения итерационного параметра вычислять по формуле



1. В методе ПВР получить решение при оптимальном значении параметра , которое необходимо определить, варьируя параметр в диапазоне (0, 2) с шагом 0.1, и производя вычисления с критерием остановки(или по критерию минимальности нормы вектора невязки при заданном числе итераций).
2. Провести анализ эффективности рассматриваемых методов.
3. Сравнить решение, полученное итерационным методом, с решением полученным прямым методом.
4. Сравнить фактическое число итераций, необходимое для достижения заданной точности, с теоретической оценкой, вычислив число обусловленности.
5. **Исходные данные**

|  |  |
| --- | --- |
| Вариант №3: | Вариант №6 |
|  |  |

1. **Решение**

В данном разделе будут приведены результаты, а также подробные шаги выполнения программы, на примере двух наборов: №3 и №6.

Программа считывает из файла «input.txt» матрицу , а так же вектор, затем автоматически генерирует файл «output.txt» и выводит в него все необходимые данные.

# **Набор №3. а)**

Файл «data.txt»:

5.5 -2.6 1.0 -1.7

-2.6 7.5 -2.5 -0.4

1.0 -2.5 0.9 0.4

-1.7 -0.4 0.4 4.9

1 2 3 4

Файл «output.txt»:

Вектор b:

1.0000000 2.0000000 3.0000000 4.0000000

Исходная матрица А:

5.5000000 -2.6000000 1.0000000 -1.7000000

-2.6000000 7.5000000 -2.5000000 -0.4000000

1.0000000 -2.5000000 0.9000000 0.4000000

-1.7000000 -0.4000000 0.4000000 4.9000000

Норма матрицы А: 13.0000000

**МЕТОД ПРОСТОЙ ИТЕРАЦИИ**

Значения итерационного параметра: 0.1384615

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.1384615 0.5538462 7.2222222 0.5538462 0.1384615 0.2769231 0.4153846 0.5538462

2 0.1384615 0.7396154 3.5859368 0.4096331 0.3440237 0.4905799 0.8250178 0.7568521

3 0.1384615 0.9590016 2.3296415 0.3928388 0.4610248 0.7094042 1.2178566 0.8596584

4 0.1384615 1.0124709 1.7780151 0.3977379 0.5375078 0.8847848 1.6155944 0.9106171

5 0.1384615 0.9942981 1.4202292 0.3954700 0.5758066 1.0460741 2.0110645 0.9326900

6 0.1384615 1.0000603 1.1869002 0.3954939 0.5934417 1.1917742 2.4065583 0.9358323

7 0.1384615 0.9962938 1.0161295 0.3940281 0.5960780 1.3295948 2.8005864 0.9271589

8 0.1384615 0.9967528 0.8882618 0.3927486 0.5897228 1.4611570 3.1933350 0.9108007

9 0.1384615 0.9958859 0.7880802 0.3911328 0.5773387 1.5888545 3.5844678 0.8895793

10 0.1384615 0.9957863 0.7078456 0.3894847 0.5612046 1.7137015 3.9739525 0.8652505

11 0.1384615 0.9955374 0.6420415 0.3877466 0.5426469 1.8365656 4.3616990 0.8389732

12 0.1384615 0.9954495 0.5871601 0.3859821 0.5225794 1.9579239 4.7476812 0.8114855

13 0.1384615 0.9953633 0.5406842 0.3841924 0.5015692 2.0781188 5.1318736 0.7832675

14 0.1384615 0.9953190 0.5008343 0.3823940 0.4799913 2.1973591 5.5142676 0.7546274

15 0.1384615 0.9952856 0.4662902 0.3805913 0.4580840 2.3157858 5.8948589 0.7257647

16 0.1384615 0.9952658 0.4360623 0.3787895 0.4360025 2.4334889 6.2736483 0.6968078

17 0.1384615 0.9952522 0.4093912 0.3769911 0.4138462 2.5505282 6.6506394 0.6678392

18 0.1384615 0.9952437 0.3856854 0.3751980 0.3916794 2.6669429 7.0258374 0.6389121

19 0.1384615 0.9952381 0.3644775 0.3734113 0.3695433 2.7827595 7.3992487 0.6100606

20 0.1384615 0.9952344 0.3453930 0.3716318 0.3474643 2.8979958 7.7708805 0.5813064

21 0.1384615 0.9952321 0.3281287 0.3698599 0.3254594 3.0126644 8.1407403 0.5526634

22 0.1384615 0.9952306 0.3124364 0.3680958 0.3035393 3.1267744 8.5088362 0.5241403

23 0.1384615 0.9952296 0.2981110 0.3663399 0.2817108 3.2403324 8.8751760 0.4957425

24 0.1384615 0.9952289 0.2849817 0.3645920 0.2599780 3.3533436 9.2397681 0.4674732

25 0.1384615 0.9952285 0.2729047 0.3628524 0.2383435 3.4658125 9.6026205 0.4393342

26 0.1384615 0.9952282 0.2617587 0.3611209 0.2168087 3.5777426 9.9637414 0.4113266

27 0.1384615 0.9952281 0.2514400 0.3593977 0.1953744 3.6891373 10.3231391 0.3834508

28 0.1384615 0.9952279 0.2418600 0.3576826 0.1740410 3.7999995 10.6808217 0.3557068

29 0.1384615 0.9952279 0.2329422 0.3559757 0.1528084 3.9103322 11.0367974 0.3280945

30 0.1384615 0.9952278 0.2246203 0.3542769 0.1316765 4.0201379 11.3910743 0.3006133

31 0.1384615 0.9952278 0.2168367 0.3525862 0.1106451 4.1294195 11.7436605 0.2732631

32 0.1384615 0.9952278 0.2095407 0.3509036 0.0897137 4.2381793 12.0945642 0.2460431

33 0.1384615 0.9952278 0.2026882 0.3492290 0.0688822 4.3464200 12.4437932 0.2189528

34 0.1384615 0.9952277 0.1962398 0.3475624 0.0481499 4.4541441 12.7913556 0.1919918

35 0.1384615 0.9952277 0.1901610 0.3459037 0.0275165 4.5613541 13.1372593 0.1651594

36 0.1384615 0.9952277 0.1844208 0.3442530 0.0069815 4.6680524 13.4815123 0.1384550

37 0.1384615 0.9952277 0.1789919 0.3426101 -0.0134555 4.7742416 13.8241225 0.1118780

38 0.1384615 0.9952277 0.1738497 0.3409751 -0.0337950 4.8799239 14.1650976 0.0854278

39 0.1384615 0.9952277 0.1689720 0.3393479 -0.0540375 4.9851019 14.5044455 0.0591039

40 0.1384615 0.9952277 0.1643391 0.3377284 -0.0741833 5.0897779 14.8421739 0.0329056

41 0.1384615 0.9952277 0.1599330 0.3361167 -0.0942330 5.1939544 15.1782906 0.0068322

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44 0.1384615 0.9952277 0.1479207 0.3313275 -0.1538099 5.5035104 16.1770470 -0.0706435

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47 0.1384615 0.9952277 0.1374481 0.3266065 -0.2125380 5.8086557 17.1615725 -0.1470153

48 0.1384615 0.9952277 0.1342494 0.3250479 -0.2319274 5.9094015 17.4866204 -0.1722300

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124 0.1384615 0.9952277 0.0427810 0.2259721 -1.4644165 12.3132990 38.1482569 -1.7749992

125 0.1384615 0.9952277 0.0423273 0.2248937 -1.4778317 12.3830029 38.3731506 -1.7924447

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1221 0.1384615 0.9952277 0.0001010 0.0011885 -4.2606946 26.8424973 85.0254927 -5.4113707

1222 0.1384615 0.9952277 0.0001005 0.0011828 -4.2607651 26.8428639 85.0266755 -5.4114624

1223 0.1384615 0.9952277 0.0001000 0.0011772 -4.2608354 26.8432288 85.0278527 -5.4115537

Получили:

Число итераций: 1223

Норма невязки: 0.0001

Оценка нормы матрицы перехода q: 0.9952277

Последнее приближение: -4.2608354 26.8432288 85.0278527 -5.4115537

**ГРАДИЕНТНЫЙ МЕТОД НАИСКОРЕЙШЕГО СПУСКА**

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.3886010 1.5544041 2.5733333 1.5544041 0.3886010 0.7772021 1.1658031 1.5544041

2 0.2327695 0.4659270 1.6937619 0.7242389 0.9379613 0.9442413 1.8369754 0.8301653

3 0.2377006 0.7999394 1.0086808 0.5793472 0.4317888 1.4865300 2.4163226 1.1081872

4 0.1768391 1.1191786 1.1963821 0.6483930 0.7779929 1.2138012 3.0647156 0.9193242

5 0.2242767 1.0199757 0.8323934 0.6613451 0.4135562 1.8751464 3.5425453 0.9367132

6 0.1765525 0.9907768 0.8841159 0.6552454 0.7049895 1.5648900 4.1977907 0.8389369

7 0.2242625 1.0015639 0.6269873 0.6562702 0.3505817 2.2211602 4.6673176 0.8466809

8 0.1765523 0.9854504 0.6893176 0.6467217 0.6363946 1.9139199 5.3140393 0.7528945

9 0.2242624 1.0009401 0.4996461 0.6473297 0.2869719 2.5612496 5.7770543 0.7602144

10 0.1765523 0.9853302 0.5631770 0.6378335 0.5687871 2.2581934 6.4148878 0.6677857

11 0.2242624 1.0009108 0.4142790 0.6384145 0.2241679 2.8966079 6.8715272 0.6749868

12 0.1765523 0.9853359 0.4750276 0.6290527 0.5020978 2.5977208 7.5005799 0.5838298

13 0.2242624 1.0009075 0.3531070 0.6296236 0.1622206 3.2273443 7.9509326 0.5909292

14 0.1765523 0.9853383 0.4099634 0.6203922 0.4363231 2.9325716 8.5713248 0.5010264

15 0.2242624 1.0009068 0.3071247 0.6209548 0.1011246 3.5535264 9.0154772 0.5080276

16 0.1765523 0.9853389 0.3599702 0.6118509 0.3714532 3.2628119 9.6273282 0.4193624

17 0.2242624 1.0009066 0.2713021 0.6124056 0.0408693 3.8752175 10.0653657 0.4262670

18 0.1765523 0.9853391 0.3203585 0.6034272 0.3074761 3.5885054 10.6687929 0.3388225

19 0.2242624 1.0009066 0.2426094 0.6039743 -0.0185564 4.1924797 11.1007997 0.3456320

20 0.1765523 0.9853391 0.2882016 0.5951194 0.2443798 3.9097149 11.6959191 0.2593914

21 0.2242624 1.0009066 0.2191127 0.5956590 -0.0771641 4.5053739 12.1219783 0.2661072

22 0.1765523 0.9853391 0.2615784 0.5869261 0.1821521 4.2265021 12.7089043 0.1810538

23 0.2242624 1.0009066 0.1995196 0.5874582 -0.1349648 4.8139603 13.1290976 0.1876772

24 0.1765523 0.9853391 0.2391757 0.5788455 0.1207812 4.5389279 13.7079431 0.1037948

25 0.2242624 1.0009066 0.1829333 0.5793703 -0.1919698 5.1182982 14.1223514 0.1103270

26 0.1765523 0.9853391 0.2200652 0.5708762 0.0602552 4.8470523 14.6932276 0.0275995

27 0.2242624 1.0009066 0.1687122 0.5713937 -0.2481900 5.4184461 15.1019304 0.0340417

28 0.1765523 0.9853391 0.2035724 0.5630166 0.0005625 5.1509346 15.6649470 -0.0475468

29 0.2242624 1.0009066 0.1563852 0.5635270 -0.3036361 5.7144616 16.0680229 -0.0411933

30 0.1765523 0.9853391 0.1891952 0.5552652 -0.0583084 5.4506332 16.6232881 -0.1216585

31 0.2242624 1.0009066 0.1455986 0.5557686 -0.3583189 6.0064018 17.0208147 -0.1153925

32 0.1765523 0.9853391 0.1765523 0.5476205 -0.1163687 5.7462056 17.5684352 -0.1947499

33 0.2242624 1.0009066 0.1360813 0.5481170 -0.4122488 6.2943226 17.9604888 -0.1885702

34 0.1765523 0.9853391 0.1653486 0.5400811 -0.1736297 6.0377087 18.5005699 -0.2668350

35 0.2242624 1.0009066 0.1276227 0.5405707 -0.4654363 6.5782795 18.8872259 -0.2607403

36 0.1765523 0.9853391 0.1553526 0.5326455 -0.2301024 6.3251985 19.4198714 -0.3379277

37 0.2242624 1.0009066 0.1200559 0.5331284 -0.5178914 6.8583269 19.8012040 -0.3319169

38 0.1765523 0.9853391 0.1463798 0.5253122 -0.2857976 6.6087303 20.3265162 -0.4080416

39 0.2242624 1.0009066 0.1132478 0.5257885 -0.5696244 7.1345188 20.7025988 -0.4021135

40 0.1765523 0.9853391 0.1382815 0.5180799 -0.3407259 6.8883585 21.2206787 -0.4771901

41 0.2242624 1.0009066 0.1070901 0.5185496 -0.6206452 7.4069081 21.5915835 -0.4713437

42 0.1765523 0.9853391 0.1309365 0.5109472 -0.3948981 7.1641369 22.1025307 -0.5453867

43 0.2242624 1.0009066 0.1014944 0.5114104 -0.6709635 7.6755473 22.4683291 -0.5396208

44 0.1765523 0.9853391 0.1242449 0.5039127 -0.4483244 7.4361185 22.9722418 -0.6126444

45 0.2242624 1.0009066 0.0963877 0.5043695 -0.7205891 7.9404880 23.3330040 -0.6069578

46 0.1765523 0.9853391 0.1181238 0.4969750 -0.5010152 7.7043555 23.8299790 -0.6789761

47 0.2242624 1.0009066 0.0917089 0.4974256 -0.7695314 8.2017811 24.1857743 -0.6733678

48 0.1765523 0.9853391 0.1125038 0.4901329 -0.5529805 7.9688996 24.6759072 -0.7443945

49 0.2242624 1.0009066 0.0874068 0.4905772 -0.8177999 8.4594768 25.0268041 -0.7388635

50 0.1765523 0.9853391 0.1073263 0.4833849 -0.6042304 8.2298015 25.5101890 -0.8089123

51 0.2242624 1.0009066 0.0834381 0.4838231 -0.8654039 8.7136246 25.8562549 -0.8034574

52 0.1765523 0.9853391 0.1025413 0.4767298 -0.6547747 8.4871115 26.3329847 -0.8725419

53 0.2242624 1.0009066 0.0797658 0.4771620 -0.9123525 8.9642735 26.6742861 -0.8671621

54 0.1765523 0.9853391 0.0981064 0.4701664 -0.7046232 8.7408788 27.1444525 -0.9352954

55 0.2242624 1.0009066 0.0763581 0.4705927 -0.9586547 9.2114715 27.4810550 -0.9299897

56 0.1765523 0.9853391 0.0939847 0.4636934 -0.7537853 8.9911525 27.9447484 -0.9971849

57 0.2242624 1.0009066 0.0731878 0.4641137 -1.0043195 9.4552662 28.2767166 -0.9919523

58 0.1765523 0.9853391 0.0901447 0.4573094 -0.8022706 9.2379804 28.7340260 -1.0582224

59 0.2242624 1.0009066 0.0702312 0.4577240 -1.0493555 9.6957044 29.0614239 -1.0530618

60 0.1765523 0.9853391 0.0865588 0.4510133 -0.8500884 9.4814101 29.5124372 -1.1184196

61 0.2242624 1.0009066 0.0674677 0.4514222 -1.0937715 9.9328324 29.8353276 -1.1133300

62 0.1765523 0.9853391 0.0832027 0.4448040 -0.8972478 9.7214884 30.2801316 -1.1777879

63 0.2242624 1.0009066 0.0648790 0.4452072 -1.1375760 10.1666956 30.5985765 -1.1727684

64 0.1765523 0.9853391 0.0800555 0.4386801 -0.9437580 9.9582614 31.0372566 -1.2363390

65 0.2242624 1.0009066 0.0624495 0.4390778 -1.1807774 10.3973392 31.3513174 -1.2313885

66 0.1765523 0.9853391 0.0770985 0.4326405 -0.9896278 10.1917746 31.7839579 -1.2940839

67 0.2242624 1.0009066 0.0601651 0.4330327 -1.2233841 10.6248073 32.0936947 -1.2892016

68 0.1765523 0.9853391 0.0743152 0.4266841 -1.0348662 10.4220728 32.5203788 -1.3510338

69 0.2242624 1.0009066 0.0580133 0.4270709 -1.2654041 10.8491437 32.8258513 -1.3462187

70 0.1765523 0.9853391 0.0716910 0.4208097 -1.0794816 10.6492004 33.2466610 -1.4071996

71 0.2242624 1.0009066 0.0559831 0.4211912 -1.3068457 11.0703916 33.5479279 -1.4024508

72 0.1765523 0.9853391 0.0692128 0.4150161 -1.1234829 10.8732010 33.9629440 -1.4625922

73 0.2242624 1.0009066 0.0540647 0.4153924 -1.3477167 11.2885934 34.2600632 -1.4579088

74 0.1765523 0.9853391 0.0668690 0.4093023 -1.1668783 11.0941177 34.6693656 -1.5172221

75 0.2242624 1.0009066 0.0522493 0.4096734 -1.3880250 11.5037911 34.9623941 -1.5126032

76 0.1765523 0.9853391 0.0646492 0.4036672 -1.2096763 11.3119928 35.3660613 -1.5710999

77 0.2242624 1.0009066 0.0505288 0.4040332 -1.4277783 11.7160260 35.6550556 -1.5665446

78 0.1765523 0.9853391 0.0625441 0.3981097 -1.2518851 11.5268683 36.0531653 -1.6242360

79 0.2242624 1.0009066 0.0488964 0.3984706 -1.4669843 11.9253390 36.3381808 -1.6197434

80 0.1765523 0.9853391 0.0605450 0.3926287 -1.2935128 11.7387856 36.7308095 -1.6766404

81 0.2242624 1.0009066 0.0473454 0.3929846 -1.5056506 12.1317702 37.0119010 -1.6722097

82 0.1765523 0.9853391 0.0586444 0.3872231 -1.3345673 11.9477852 37.3991241 -1.7283235

83 0.2242624 1.0009066 0.0458701 0.3875742 -1.5437845 12.3353593 37.6763457 -1.7239537

84 0.1765523 0.9853391 0.0568353 0.3818920 -1.3750567 12.1539074 38.0582376 -1.7792949

85 0.2242624 1.0009066 0.0444652 0.3822382 -1.5813934 12.5361456 38.3316425 -1.7749853

86 0.1765523 0.9853391 0.0551116 0.3766342 -1.4149885 12.3571917 38.7082768 -1.8295646

87 0.2242624 1.0009066 0.0431259 0.3769757 -1.6184845 12.7341674 38.9779175 -1.8253144

88 0.1765523 0.9853391 0.0534673 0.3714489 -1.4543707 12.5576774 39.3493664 -1.8791422

89 0.2242624 1.0009066 0.0418479 0.3717856 -1.6550650 12.9294630 39.6152948 -1.8749505

90 0.1765523 0.9853391 0.0518973 0.3663349 -1.4932106 12.7554028 39.9816298 -1.9280373

91 0.2242624 1.0009066 0.0406271 0.3666670 -1.6911418 13.1220699 40.2438970 -1.9239032

92 0.1765523 0.9853391 0.0503968 0.3612914 -1.5315158 12.9504061 40.6051884 -1.9762591

93 0.2242624 1.0009066 0.0394598 0.3616189 -1.7267220 13.3120250 40.8638448 -1.9721820

94 0.1765523 0.9853391 0.0489614 0.3563173 -1.5692936 13.1427246 41.2201621 -2.0238171

95 0.2242624 1.0009066 0.0383429 0.3566403 -1.7618123 13.4993648 41.4752575 -2.0197961

96 0.1765523 0.9853391 0.0475871 0.3514116 -1.6065513 13.3323953 41.8266691 -2.0707203

97 0.2242624 1.0009066 0.0372731 0.3517302 -1.7964195 13.6841255 42.0782524 -2.0667547

98 0.1765523 0.9853391 0.0462703 0.3465735 -1.6432960 13.5194547 42.4248259 -2.1169778

99 0.2242624 1.0009066 0.0362476 0.3468877 -1.8305502 13.8663424 42.6729455 -2.1130668

100 0.1765523 0.9853391 0.0450074 0.3418020 -1.6795349 13.7039388 43.0147476 -2.1625984

101 0.2242624 1.0009066 0.0352639 0.3421119 -1.8642110 14.0460507 43.2594512 -2.1587412

102 0.1765523 0.9853391 0.0437954 0.3370962 -1.7152749 13.8858829 43.5965474 -2.2075909

103 0.2242624 1.0009066 0.0343195 0.3374018 -1.8974084 14.2232848 43.8378820 -2.2037869

104 0.1765523 0.9853391 0.0426314 0.3324552 -1.7505227 14.0653222 44.1703373 -2.2519640

105 0.2242624 1.0009066 0.0334122 0.3327566 -1.9301488 14.3980788 44.4083493 -2.2482123

106 0.1765523 0.9853391 0.0415126 0.3278781 -1.7852854 14.2422909 44.7362274 -2.2957262

107 0.2242624 1.0009066 0.0325400 0.3281754 -1.9624383 14.5704663 44.9709626 -2.2920262

108 0.1765523 0.9853391 0.0404366 0.3233640 -1.8195694 14.4168233 45.2943266 -2.3388859

109 0.2242624 1.0009066 0.0317008 0.3236572 -1.9942834 14.7404804 45.5258300 -2.3352368

110 0.1765523 0.9853391 0.0394011 0.3189121 -1.8533814 14.5889527 45.8447421 -2.3814513

111 0.2242624 1.0009066 0.0308931 0.3192012 -2.0256900 14.9081539 46.0730582 -2.3778525

112 0.1765523 0.9853391 0.0384039 0.3145214 -1.8867279 14.7587123 46.3875797 -2.4234308

113 0.2242624 1.0009066 0.0301150 0.3148066 -2.0566642 15.0735189 46.6127525 -2.4198815

114 0.1765523 0.9853391 0.0374430 0.3101912 -1.9196153 14.9261348 46.9229437 -2.4648323

115 0.2242624 1.0009066 0.0293650 0.3104724 -2.0872120 15.2366072 47.1450164 -2.4613318

116 0.1765523 0.9853391 0.0365166 0.3059206 -1.9520499 15.0912522 47.4509370 -2.5056638

117 0.2242624 1.0009066 0.0286418 0.3061980 -2.1173392 15.3974502 47.6699523 -2.5022115

118 0.1765523 0.9853391 0.0356230 0.3017088 -1.9840380 15.2540964 47.9716611 -2.5459331

119 0.2242624 1.0009066 0.0279440 0.3019823 -2.1470516 15.5560788 48.1876611 -2.5425284

120 0.1765523 0.9853391 0.0347604 0.2975550 -2.0155856 15.4146986 48.4852161 -2.5856480

121 0.2242624 1.0009066 0.0272704 0.2978248 -2.1763550 15.7125234 48.6982423 -2.5822902

122 0.1765523 0.9853391 0.0339274 0.2934584 -2.0466990 15.5730897 48.9917007 -2.6248162

123 0.2242624 1.0009066 0.0266197 0.2937244 -2.2052549 15.8668141 49.2017940 -2.6215046

124 0.1765523 0.9853391 0.0331226 0.2894182 -2.0773839 15.7293001 49.4912122 -2.6634451

125 0.2242624 1.0009066 0.0259908 0.2896806 -2.2337570 16.0189807 49.6984130 -2.6601791

126 0.1765523 0.9853391 0.0323446 0.2854336 -2.1076464 15.8833599 49.9838466 -2.7015421

127 0.2242624 1.0009066 0.0253829 0.2856923 -2.2618666 16.1690522 50.1881948 -2.6983211

128 0.1765523 0.9853391 0.0315922 0.2815038 -2.1374923 16.0352986 50.4696986 -2.7391147

129 0.2242624 1.0009066 0.0247948 0.2817590 -2.2895892 16.3170577 50.6712334 -2.7359380

130 0.1765523 0.9853391 0.0308643 0.2776282 -2.1669273 16.1851455 50.9488616 -2.7761700

131 0.2242624 1.0009066 0.0242256 0.2778799 -2.3169302 16.4630254 51.1476218 -2.7730370

132 0.1765523 0.9853391 0.0301596 0.2738059 -2.1959570 16.3329294 51.4214277 -2.8127151

133 0.2242624 1.0009066 0.0236746 0.2740542 -2.3438947 16.6069836 51.6174514 -2.8096253

134 0.1765523 0.9853391 0.0294772 0.2700363 -2.2245871 16.4786787 51.8874877 -2.8487571

135 0.2242624 1.0009066 0.0231410 0.2702811 -2.3704880 16.7489598 52.0808126 -2.8457098

136 0.1765523 0.9853391 0.0288161 0.2663185 -2.2528229 16.6224213 52.3471311 -2.8843028

137 0.2242624 1.0009066 0.0226239 0.2665600 -2.3967152 16.8889813 52.5377944 -2.8812975

138 0.1765523 0.9853391 0.0281754 0.2626520 -2.2806701 16.7641849 52.8004463 -2.9193592

139 0.2242624 1.0009066 0.0221226 0.2628901 -2.4225813 17.0270750 52.9884847 -2.9163953

140 0.1765523 0.9853391 0.0275542 0.2590359 -2.3081338 16.9039968 53.2475205 -2.9539330

141 0.2242624 1.0009066 0.0216365 0.2592707 -2.4480913 17.1632675 53.4329700 -2.9510098

142 0.1765523 0.9853391 0.0269516 0.2554696 -2.3352195 17.0418838 53.6884396 -2.9880307

143 0.2242624 1.0009066 0.0211650 0.2557012 -2.4732500 17.2975850 53.8713358 -2.9851478

144 0.1765523 0.9853391 0.0263670 0.2519524 -2.3619322 17.1778725 54.1232882 -3.0216590

145 0.2242624 1.0009066 0.0207074 0.2521808 -2.4980624 17.4300532 54.3036664 -3.0188158

146 0.1765523 0.9853391 0.0257996 0.2484836 -2.3882772 17.3119889 54.5521500 -3.0548243

147 0.2242624 1.0009066 0.0202632 0.2487088 -2.5225332 17.5606977 54.7300449 -3.0520203

148 0.1765523 0.9853391 0.0252486 0.2450626 -2.4142594 17.4442588 54.9751074 -3.0875330

149 0.2242624 1.0009066 0.0198319 0.2452847 -2.5466671 17.6895435 55.1505531 -3.0847676

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151 0.2242624 1.0009066 0.0194129 0.2419077 -2.5704687 17.8166155 55.5652719 -3.1170640

152 0.1765523 0.9853391 0.0241936 0.2383612 -2.4651557 17.7033606 55.8036331 -3.1516057

153 0.2242624 1.0009066 0.0190057 0.2385772 -2.5939426 17.9419379 55.9742811 -3.1489159

154 0.1765523 0.9853391 0.0236882 0.2350795 -2.4900796 17.8302423 56.2093605 -3.1829820

155 0.2242624 1.0009066 0.0186099 0.2352926 -2.6170933 18.0655349 56.3776591 -3.1803291

156 0.1765523 0.9853391 0.0231970 0.2318430 -2.5146603 17.9553772 56.6095021 -3.2139263

157 0.2242624 1.0009066 0.0182251 0.2320532 -2.6399253 18.1874304 56.7754836 -3.2113100

158 0.1765523 0.9853391 0.0227192 0.2286511 -2.5389025 18.0787892 57.0041347 -3.2444445

159 0.2242624 1.0009066 0.0178508 0.2288584 -2.6624430 18.3076476 57.1678311 -3.2418642

160 0.1765523 0.9853391 0.0222545 0.2255031 -2.5628110 18.2005021 57.3933342 -3.2745426

161 0.2242624 1.0009066 0.0174867 0.2257075 -2.6846507 18.4262097 57.5547768 -3.2719979

162 0.1765523 0.9853391 0.0218023 0.2223985 -2.5863904 18.3205394 57.7771753 -3.3042263

163 0.2242624 1.0009066 0.0171324 0.2226001 -2.7065526 18.5431394 57.9363952 -3.3017166

164 0.1765523 0.9853391 0.0213622 0.2193366 -2.6096451 18.4389240 58.1557318 -3.3335014

165 0.2242624 1.0009066 0.0167874 0.2195354 -2.7281529 18.6584594 58.3127597 -3.3310262

166 0.1765523 0.9853391 0.0209337 0.2163168 -2.6325797 18.5556787 58.5290765 -3.3623734

167 0.2242624 1.0009066 0.0164516 0.2165129 -2.7494559 18.7721916 58.6839425 -3.3599323

168 0.1765523 0.9853391 0.0205164 0.2133387 -2.6551985 18.6708260 58.8972812 -3.3908479

169 0.2242624 1.0009066 0.0161245 0.2135321 -2.7704656 18.8843581 59.0500150 -3.3884404

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707 0.2242624 1.0009066 0.0002701 0.0051273 -4.2393416 26.7263856 84.6436835 -5.3815619

708 0.1765523 0.9853391 0.0003380 0.0050521 -4.2371095 26.7239852 84.6487356 -5.3822940

709 0.2242624 1.0009066 0.0002664 0.0050567 -4.2398392 26.7290418 84.6523525 -5.3822370

710 0.1765523 0.9853391 0.0003334 0.0049825 -4.2376378 26.7266744 84.6573350 -5.3829590

711 0.2242624 1.0009066 0.0002627 0.0049870 -4.2403298 26.7316615 84.6609021 -5.3829028

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714 0.1765523 0.9853391 0.0003242 0.0048463 -4.2386726 26.7319424 84.6741803 -5.3842617

715 0.2242624 1.0009066 0.0002554 0.0048507 -4.2412910 26.7367931 84.6776499 -5.3842070

716 0.1765523 0.9853391 0.0003197 0.0047796 -4.2391793 26.7345221 84.6824295 -5.3848997

717 0.2242624 1.0009066 0.0002519 0.0047839 -4.2417617 26.7393060 84.6858512 -5.3848457

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719 0.2242624 1.0009066 0.0002484 0.0047180 -4.2422259 26.7417843 84.6939397 -5.3854756

720 0.1765523 0.9853391 0.0003109 0.0046489 -4.2401720 26.7395755 84.6985885 -5.3861493

721 0.2242624 1.0009066 0.0002450 0.0046531 -4.2426838 26.7442286 84.7019168 -5.3860968

722 0.1765523 0.9853391 0.0003066 0.0045849 -4.2406581 26.7420501 84.7065016 -5.3867612

723 0.2242624 1.0009066 0.0002416 0.0045890 -4.2431353 26.7466391 84.7097840 -5.3867095

724 0.1765523 0.9853391 0.0003023 0.0045217 -4.2411375 26.7444907 84.7143057 -5.3873647

725 0.2242624 1.0009066 0.0002382 0.0045258 -4.2435806 26.7490165 84.7175429 -5.3873137

726 0.1765523 0.9853391 0.0002981 0.0044595 -4.2416103 26.7468976 84.7220024 -5.3879600

727 0.2242624 1.0009066 0.0002349 0.0044635 -4.2440197 26.7513611 84.7251951 -5.3879096

728 0.1765523 0.9853391 0.0002940 0.0043981 -4.2420766 26.7492714 84.7295931 -5.3885470

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731 0.2242624 1.0009066 0.0002284 0.0043415 -4.2448800 26.7559540 84.7401847 -5.3890770

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738 0.1765523 0.9853391 0.0002742 0.0041035 -4.2443135 26.7606592 84.7660076 -5.3913630

739 0.2242624 1.0009066 0.0002161 0.0041073 -4.2465307 26.7647665 84.7689454 -5.3913167

740 0.1765523 0.9853391 0.0002704 0.0040471 -4.2447426 26.7628436 84.7729925 -5.3919032

741 0.2242624 1.0009066 0.0002131 0.0040507 -4.2469292 26.7668943 84.7758898 -5.3918575

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747 0.2242624 1.0009066 0.0002043 0.0038857 -4.2480923 26.7731035 84.7961547 -5.3934357

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754 0.1765523 0.9853391 0.0002453 0.0036728 -4.2475852 26.7773148 84.8192668 -5.3954817

755 0.2242624 1.0009066 0.0001933 0.0036761 -4.2495696 26.7809909 84.8218962 -5.3954403

756 0.1765523 0.9853391 0.0002419 0.0036222 -4.2479693 26.7792698 84.8255185 -5.3959652

757 0.2242624 1.0009066 0.0001906 0.0036255 -4.2499264 26.7828953 84.8281117 -5.3959243

758 0.1765523 0.9853391 0.0002385 0.0035723 -4.2483480 26.7811980 84.8316840 -5.3964420

759 0.2242624 1.0009066 0.0001879 0.0035756 -4.2502782 26.7847735 84.8342415 -5.3964017

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761 0.2242624 1.0009066 0.0001853 0.0035263 -4.2506251 26.7866259 84.8402870 -5.3968725

762 0.1765523 0.9853391 0.0002320 0.0034746 -4.2490900 26.7849749 84.8437616 -5.3973760

763 0.2242624 1.0009066 0.0001828 0.0034778 -4.2509673 26.7884527 84.8462492 -5.3973368

764 0.1765523 0.9853391 0.0002288 0.0034268 -4.2494533 26.7868245 84.8496760 -5.3978334

765 0.2242624 1.0009066 0.0001802 0.0034299 -4.2513048 26.7902544 84.8521293 -5.3977947

766 0.1765523 0.9853391 0.0002256 0.0033796 -4.2498116 26.7886486 84.8555090 -5.3982845

767 0.2242624 1.0009066 0.0001778 0.0033827 -4.2516376 26.7920313 84.8579285 -5.3982463

768 0.1765523 0.9853391 0.0002225 0.0033331 -4.2501650 26.7904476 84.8612616 -5.3987293

769 0.2242624 1.0009066 0.0001753 0.0033361 -4.2519659 26.7937838 84.8636478 -5.3986917

770 0.1765523 0.9853391 0.0002194 0.0032872 -4.2505135 26.7922219 84.8669351 -5.3991681

771 0.2242624 1.0009066 0.0001729 0.0032902 -4.2522896 26.7955121 84.8692884 -5.3991310

772 0.1765523 0.9853391 0.0002164 0.0032420 -4.2508572 26.7939717 84.8725304 -5.3996008

773 0.2242624 1.0009066 0.0001705 0.0032449 -4.2526088 26.7972166 84.8748514 -5.3995642

774 0.1765523 0.9853391 0.0002134 0.0031973 -4.2511962 26.7956974 84.8780487 -5.4000275

775 0.2242624 1.0009066 0.0001681 0.0032002 -4.2529237 26.7988976 84.8803377 -5.3999915

776 0.1765523 0.9853391 0.0002104 0.0031533 -4.2515305 26.7973994 84.8834910 -5.4004484

777 0.2242624 1.0009066 0.0001658 0.0031562 -4.2532343 26.8005555 84.8857486 -5.4004128

778 0.1765523 0.9853391 0.0002075 0.0031099 -4.2518602 26.7990779 84.8888584 -5.4008635

779 0.2242624 1.0009066 0.0001635 0.0031127 -4.2535405 26.8021906 84.8910849 -5.4008284

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784 0.1765523 0.9853391 0.0001990 0.0029832 -4.2528224 26.8039761 84.9045213 -5.4020748

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786 0.1765523 0.9853391 0.0001963 0.0029421 -4.2531344 26.8055641 84.9095992 -5.4024674

787 0.2242624 1.0009066 0.0001546 0.0029448 -4.2547240 26.8085089 84.9117055 -5.4024342

788 0.1765523 0.9853391 0.0001935 0.0029016 -4.2534420 26.8071302 84.9146072 -5.4028547

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790 0.1765523 0.9853391 0.0001909 0.0028617 -4.2537454 26.8086748 84.9195462 -5.4032367

791 0.2242624 1.0009066 0.0001504 0.0028643 -4.2552916 26.8115390 84.9215949 -5.4032044

792 0.1765523 0.9853391 0.0001882 0.0028223 -4.2540446 26.8101981 84.9244172 -5.4036134

793 0.2242624 1.0009066 0.0001483 0.0028248 -4.2555695 26.8130229 84.9264377 -5.4035815

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795 0.2242624 1.0009066 0.0001463 0.0027859 -4.2558436 26.8144863 84.9312138 -5.4039535

796 0.1765523 0.9853391 0.0001831 0.0027451 -4.2546308 26.8131820 84.9339589 -5.4043513

797 0.2242624 1.0009066 0.0001442 0.0027476 -4.2561140 26.8159296 84.9359242 -5.4043203

798 0.1765523 0.9853391 0.0001805 0.0027073 -4.2549178 26.8146433 84.9386315 -5.4047126

799 0.2242624 1.0009066 0.0001423 0.0027098 -4.2563806 26.8173530 84.9405697 -5.4046821

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801 0.2242624 1.0009066 0.0001403 0.0026725 -4.2566435 26.8187568 84.9451513 -5.4050389

802 0.1765523 0.9853391 0.0001756 0.0026333 -4.2554801 26.8175057 84.9477846 -5.4054205

803 0.2242624 1.0009066 0.0001383 0.0026357 -4.2569028 26.8201413 84.9496698 -5.4053907

804 0.1765523 0.9853391 0.0001732 0.0025970 -4.2557554 26.8189074 84.9522668 -5.4057671

805 0.2242624 1.0009066 0.0001364 0.0025994 -4.2571586 26.8215068 84.9541261 -5.4057378

806 0.1765523 0.9853391 0.0001708 0.0025613 -4.2560270 26.8202898 84.9566873 -5.4061089

807 0.2242624 1.0009066 0.0001346 0.0025636 -4.2574108 26.8228534 84.9585210 -5.4060800

808 0.1765523 0.9853391 0.0001684 0.0025260 -4.2562948 26.8216532 84.9610470 -5.4064461

809 0.2242624 1.0009066 0.0001327 0.0025283 -4.2576596 26.8241815 84.9628554 -5.4064176

810 0.1765523 0.9853391 0.0001661 0.0024912 -4.2565589 26.8229978 84.9653467 -5.4067786

811 0.2242624 1.0009066 0.0001309 0.0024935 -4.2579049 26.8254913 84.9671302 -5.4067505

812 0.1765523 0.9853391 0.0001638 0.0024569 -4.2568194 26.8243239 84.9695871 -5.4071065

813 0.2242624 1.0009066 0.0001290 0.0024592 -4.2581469 26.8267830 84.9713461 -5.4070788

814 0.1765523 0.9853391 0.0001615 0.0024231 -4.2570763 26.8256317 84.9737692 -5.4074299

815 0.2242624 1.0009066 0.0001273 0.0024253 -4.2583855 26.8280570 84.9755039 -5.4074026

816 0.1765523 0.9853391 0.0001593 0.0023897 -4.2573297 26.8269216 84.9778937 -5.4077489

817 0.2242624 1.0009066 0.0001255 0.0023919 -4.2586209 26.8293135 84.9796045 -5.4077219

818 0.1765523 0.9853391 0.0001571 0.0023568 -4.2575796 26.8281937 84.9819614 -5.4080635

819 0.2242624 1.0009066 0.0001238 0.0023590 -4.2588530 26.8305526 84.9836487 -5.4080369

820 0.1765523 0.9853391 0.0001549 0.0023244 -4.2578260 26.8294482 84.9859731 -5.4083737

821 0.2242624 1.0009066 0.0001221 0.0023265 -4.2590819 26.8317747 84.9876372 -5.4083475

822 0.1765523 0.9853391 0.0001528 0.0022924 -4.2580690 26.8306855 84.9899295 -5.4086797

823 0.2242624 1.0009066 0.0001204 0.0022945 -4.2593076 26.8329800 84.9915707 -5.4086538

824 0.1765523 0.9853391 0.0001507 0.0022608 -4.2583087 26.8319058 84.9938316 -5.4089814

825 0.2242624 1.0009066 0.0001187 0.0022629 -4.2595303 26.8341686 84.9954501 -5.4089559

826 0.1765523 0.9853391 0.0001486 0.0022297 -4.2585451 26.8331092 84.9976798 -5.4092790

827 0.2242624 1.0009066 0.0001171 0.0022317 -4.2597499 26.8353410 84.9992761 -5.4092539

828 0.1765523 0.9853391 0.0001465 0.0021990 -4.2587783 26.8342961 85.0014751 -5.4095725

829 0.2242624 1.0009066 0.0001155 0.0022010 -4.2599664 26.8364971 85.0030494 -5.4095477

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831 0.2242624 1.0009066 0.0001139 0.0021707 -4.2601800 26.8376374 85.0067708 -5.4098375

832 0.1765523 0.9853391 0.0001425 0.0021389 -4.2592350 26.8366211 85.0089097 -5.4101475

833 0.2242624 1.0009066 0.0001123 0.0021408 -4.2603906 26.8387619 85.0104410 -5.4101233

834 0.1765523 0.9853391 0.0001405 0.0021094 -4.2594586 26.8377596 85.0125504 -5.4104290

835 0.2242624 1.0009066 0.0001107 0.0021113 -4.2605984 26.8398710 85.0140606 -5.4104052

836 0.1765523 0.9853391 0.0001386 0.0020804 -4.2596792 26.8388825 85.0161409 -5.4107067

837 0.2242624 1.0009066 0.0001092 0.0020823 -4.2608032 26.8409648 85.0176303 -5.4106832

838 0.1765523 0.9853391 0.0001367 0.0020517 -4.2598967 26.8399899 85.0196821 -5.4109805

839 0.2242624 1.0009066 0.0001077 0.0020536 -4.2610053 26.8420435 85.0211510 -5.4109574

840 0.1765523 0.9853391 0.0001348 0.0020235 -4.2601113 26.8410821 85.0231745 -5.4112506

841 0.2242624 1.0009066 0.0001062 0.0020253 -4.2612046 26.8431074 85.0246231 -5.4112278

842 0.1765523 0.9853391 0.0001329 0.0019956 -4.2603229 26.8421592 85.0266188 -5.4115170

843 0.2242624 1.0009066 0.0001048 0.0019974 -4.2614011 26.8441566 85.0280475 -5.4114944

844 0.1765523 0.9853391 0.0001311 0.0019682 -4.2605315 26.8432215 85.0300156 -5.4117797

845 0.2242624 1.0009066 0.0001033 0.0019699 -4.2615949 26.8451914 85.0314247 -5.4117574

846 0.1765523 0.9853391 0.0001293 0.0019411 -4.2607373 26.8442692 85.0333657 -5.4120387

847 0.2242624 1.0009066 0.0001019 0.0019428 -4.2617861 26.8462120 85.0347554 -5.4120168

848 0.1765523 0.9853391 0.0001275 0.0019143 -4.2609403 26.8453024 85.0366697 -5.4122942

849 0.2242624 1.0009066 0.0001005 0.0019161 -4.2619746 26.8472185 85.0380403 -5.4122726

850 0.1765523 0.9853391 0.0001257 0.0018880 -4.2611405 26.8463214 85.0399282 -5.4125462

851 0.2242624 1.0009066 0.0000991 0.0018897 -4.2621605 26.8482111 85.0412799 -5.4125249

Получили:

Число итераций: 851

Норма невязки: 0.0000991

Оценка нормы матрицы перехода q: 1.0009066

Последнее приближение: -4.2621605 26.8482111 85.0412799 -5.4125249

**МЕТОД ПВР(SOR)**

Вычисление оптимального значения w:

w = 0.1 - число итераций: 796

w = 0.2 - число итераций: 388

w = 0.3 - число итераций: 252

w = 0.4 - число итераций: 183

w = 0.5 - число итераций: 142

w = 0.6 - число итераций: 114

w = 0.7 - число итераций: 94

w = 0.8 - число итераций: 78

w = 0.9 - число итераций: 66

w = 1.0 - число итераций: 56

w = 1.1 - число итераций: 48

w = 1.2 - число итераций: 41

w = 1.3 - число итераций: 35

w = 1.4 - число итераций: 29

w = 1.5 - число итераций: 23

w = 1.6 - число итераций: 17

w = 1.7 - число итераций: 13

w = 1.8 - число итераций: 20

w = 1.9 - число итераций: 27

Минимальное число итераций достигается при w = 1.7

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ w q невязки погр-ти X[1] X[2] X[3] X[4]

1 1.7000000 8.0837576 0.4948194 8.0837576 0.3090909 0.6354909 8.0837576 0.5364187

2 1.7000000 1.4817180 0.9202362 11.9778491 -1.6133215 3.6871368 20.0616067 -2.2116438

3 1.7000000 1.1082433 0.5825897 13.2743710 -2.9614454 7.2947805 33.3359777 -2.4246231

4 1.7000000 1.0577573 0.4635048 14.0410622 -3.3334233 12.0530444 47.3770399 -3.7831537

5 1.7000000 0.8256762 0.3368572 11.5933705 -4.3029357 15.9843222 58.9704103 -4.4673075

6 1.7000000 0.8662515 0.2400853 10.0427742 -4.4078563 19.6781411 69.0131846 -4.9313611

7 1.7000000 0.7479974 0.1765946 7.5119686 -4.7138940 22.5609409 76.5251532 -5.4294386

8 1.7000000 0.7228253 0.1180883 5.4298406 -4.7665432 24.7235763 81.9549938 -5.5652447

9 1.7000000 0.6716962 0.0799226 3.6472036 -4.7413906 26.2891513 85.6021973 -5.7442246

10 1.7000000 0.5777739 0.0480171 2.1072591 -4.7222076 27.2550752 87.7094564 -5.7660140

11 1.7000000 0.5065584 0.0256422 1.0674497 -4.6221682 27.8300230 88.7769062 -5.7601058

12 1.7000000 0.2482807 0.0100561 0.2650272 -4.5569813 28.0714002 89.0419333 -5.7290767

13 1.7000000 0.7938774 0.0030133 0.2103991 -4.4742457 28.1041903 88.8315342 -5.6682512

14 1.7000000 2.3077016 0.0068247 0.4855383 -4.4088158 28.0060859 88.3459960 -5.6184724

15 1.7000000 1.2465960 0.0101545 0.6052701 -4.3572250 27.8345381 87.7407259 -5.5626995

16 1.7000000 1.0065708 0.0110303 0.6092472 -4.3148111 27.6416879 87.1314787 -5.5189392

17 1.7000000 0.9140191 0.0105117 0.5568635 -4.2881755 27.4511078 86.5746151 -5.4830307

18 1.7000000 0.8349433 0.0091655 0.4649495 -4.2689877 27.2835216 86.1096656 -5.4555831

19 1.7000000 0.7845242 0.0073923 0.3647641 -4.2589634 27.1457568 85.7449015 -5.4373822

20 1.7000000 0.7325906 0.0056059 0.2672228 -4.2543842 27.0398414 85.4776787 -5.4250365

21 1.7000000 0.6783308 0.0039395 0.1812654 -4.2536239 26.9641233 85.2964133 -5.4185827

22 1.7000000 0.6164727 0.0025444 0.1117452 -4.2555872 26.9138370 85.1846681 -5.4157293

23 1.7000000 0.5207509 0.0014440 0.0581914 -4.2585860 26.8842065 85.1264767 -5.4155318

24 1.7000000 0.3495424 0.0006333 0.0203404 -4.2622088 26.8698556 85.1061363 -5.4169755

25 1.7000000 0.2270420 0.0001318 0.0046181 -4.2656773 26.8662000 85.1107544 -5.4191589

26 1.7000000 4.1501821 0.0002580 0.0191660 -4.2687618 26.8693601 85.1299205 -5.4216710

27 1.7000000 1.3550765 0.0004363 0.0259714 -4.2713071 26.8762810 85.1558919 -5.4240575

28 1.7000000 1.0584331 0.0005001 0.0274890 -4.2732451 26.8847951 85.1833809 -5.4261632

29 1.7000000 0.9315161 0.0004881 0.0256065 -4.2746494 26.8933938 85.2089874 -5.4278777

30 1.7000000 0.8556231 0.0004315 0.0219095 -4.2755717 26.9011860 85.2308969 -5.4291807

31 1.7000000 0.7973633 0.0003541 0.0174698 -4.2761207 26.9077052 85.2483667 -5.4301120

32 1.7000000 0.7462471 0.0002717 0.0130368 -4.2763865 26.9128002 85.2614035 -5.4307190

33 1.7000000 0.6946414 0.0001948 0.0090559 -4.2764543 26.9165262 85.2704594 -5.4310738

34 1.7000000 0.6342662 0.0001289 0.0057439 -4.2763980 26.9190507 85.2762033 -5.4312390

35 1.7000000 0.5523078 0.0000762 0.0031724 -4.2762708 26.9205984 85.2793757 -5.4312738

Получили:

Число итераций: 35

Норма невязки: 0.0000762

Оценка нормы матрицы перехода q: 0.5523078

Последнее приближение: -4.2762708 26.9205984 85.2793757 -5.4312738

**МЕТОД СОПРЯЖЕННЫХ ГРАДИЕНТОВ**

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.3886010 1.5544041 2.5733333 1.5544041 0.3886010 0.7772021 1.1658031 1.5544041

2 0.2327695 1.5261336 0.8794153 2.3722285 1.8065221 1.8186176 3.5380316 1.5989060

3 0.1877153 2.3122442 0.5571588 5.4851715 1.7524892 5.1448408 9.0232031 0.8988403

4 0.1514382 13.9011415 0.1068598 76.2501454 -4.2754795 26.9193181 85.2733485 -5.4305974

5 0.1831027 0.0000000 0.0000000 0.0000000 -4.2754795 26.9193181 85.2733485 -5.4305974

Получили:

Число итераций: 5

Норма невязки: 0.0000000

Оценка нормы матрицы перехода q: 0.0000000

Последнее приближение: -4.2754795 26.9193181 85.2733485 -5.4305974

**ПОДВЕДЕМ ИТОГИ:**

Решение методом LU разложения:

-4.2754795 26.9193181 85.2733485 -5.4305974

Число обусловленности: 493.3485194

**Решение методом простой итерации:**

-4.2608354 26.8432288 85.0278527 -5.4115537

Фактическое число итераций: 1223

Теоретическое число итераций: 2272

Скорость работы метода: 1.39 сек.

**Решение градиентным методом наискорейшего спуска:**

-4.2621605 26.8482111 85.0412799 -5.4125249

Фактическое число итераций: 851

Теоретическое число итераций: 2272

Скорость работы метода: 1.426 сек.

**Решение методом ПВР**:

-4.2762708 26.9205984 85.2793757 -5.4312738

Фактическое число итераций: 35

Теоретическое число итераций: 51

Скорость работы метода: 0.915 сек.

**Решение методом сопряженных градиентов:**

-4.2754795 26.9193181 85.2733485 -5.4305974

Фактическое число итераций: 5

Теоретическое число итераций: 110

Скорость работы метода: 0.005 сек.

# **Набор №6. a)**

Файл «data.txt»:

8.1 2.0 2.9 2.3

2.0 5.6 0.4 -0.4

2.9 0.4 8.5 2.3

2.3 -0.4 2.3 5.2

1 2 3 4

Файл «output.txt»:

Вектор b:

1.0000000 2.0000000 3.0000000 4.0000000

Исходная матрица А:

8.1000000 2.0000000 2.9000000 2.3000000

2.0000000 5.6000000 0.4000000 -0.4000000

2.9000000 0.4000000 8.5000000 2.3000000

2.3000000 -0.4000000 2.3000000 5.2000000

Норма матрицы А: 15.3000000

**МЕТОД ПРОСТОЙ ИТЕРАЦИИ**

Значения итерационного параметра: 0.1176471

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.1176471 0.4705882 8.5000000 0.4705882 0.1176471 0.2352941 0.3529412 0.4705882

2 0.1176471 0.6323529 4.7100515 0.2975779 -0.1799308 0.2934256 0.1743945 0.5370242

3 0.1176471 0.5288098 1.9262733 0.1573621 -0.1646733 0.3948056 0.2552086 0.6943863

4 0.1176471 0.5928260 1.0799397 0.0932883 -0.2579617 0.4294064 0.2026520 0.7342548

5 0.1176471 0.6064055 0.6080354 0.0565706 -0.2633499 0.4675109 0.2220636 0.7908254

6 0.1176471 0.5506300 0.3265598 0.0311494 -0.2944994 0.4835278 0.2068014 0.8107867

7 0.1176471 0.6761547 0.2152143 0.0210618 -0.2999281 0.4979792 0.2112738 0.8318485

8 0.1176471 0.5166111 0.1099769 0.0108808 -0.3108089 0.5049677 0.2067468 0.8409643

9 0.1176471 0.7386513 0.0804656 0.0080371 -0.3138874 0.5105543 0.2076636 0.8490014

10 0.1176471 0.4937256 0.0395431 0.0039681 -0.3178343 0.5135197 0.2062763 0.8529695

11 0.1176471 0.7871442 0.0310126 0.0031235 -0.3193181 0.5157121 0.2064096 0.8560930

12 0.1176471 0.5382679 0.0166603 0.0016813 -0.3207945 0.5169500 0.2059675 0.8577743

13 0.1176471 0.7316416 0.0121719 0.0012301 -0.3214593 0.5178196 0.2059580 0.8590044

14 0.1176471 0.5698398 0.0069304 0.0007010 -0.3220249 0.5183311 0.2058111 0.8597053

15 0.1176471 0.6976024 0.0048319 0.0004890 -0.3223113 0.5186785 0.2057903 0.8601943

16 0.1176471 0.5917185 0.0028582 0.0002893 -0.3225318 0.5188885 0.2057394 0.8604837

17 0.1176471 0.6761682 0.0019322 0.0001956 -0.3226525 0.5190280 0.2057264 0.8606793

18 0.1176471 0.6066410 0.0011720 0.0001187 -0.3227395 0.5191138 0.2057081 0.8607980

19 0.1176471 0.6624470 0.0007763 0.0000786 -0.3227897 0.5191700 0.2057016 0.8608766

20 0.1176471 0.6167082 0.0004787 0.0000485 -0.3228243 0.5192050 0.2056948 0.8609251

21 0.1176471 0.6535708 0.0003129 0.0000317 -0.3228450 0.5192277 0.2056919 0.8609568

22 0.1176471 0.6234494 0.0001951 0.0000198 -0.3228589 0.5192419 0.2056893 0.8609765

23 0.1176471 0.6477899 0.0001264 0.0000128 -0.3228673 0.5192511 0.2056880 0.8609893

24 0.1176471 0.6279410 0.0000793 0.0000080 -0.3228729 0.5192569 0.2056870 0.8609974

Получили:

Число итераций: 24

Норма невязки: 0.0000793

Оценка нормы матрицы перехода q: 0.6279410

Последнее приближение: -0.3228729 0.5192569 0.2056870 0.8609974

**ГРАДИЕНТНЫЙ МЕТОД НАИСКОРЕЙШЕГО СПУСКА**

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.1043115 0.4172462 9.5866667 0.4172462 0.1043115 0.2086231 0.3129346 0.4172462

2 0.1550524 0.7912842 3.7675399 0.3301603 -0.2258488 0.3117038 0.1570196 0.5651821

3 0.1048959 0.4270179 1.9032925 0.1409844 -0.1785731 0.4029025 0.2509742 0.7061665

4 0.1550251 0.7822171 0.9407515 0.1102804 -0.2888535 0.4467698 0.1888459 0.7561733

5 0.1048983 0.4533630 0.5912198 0.0499970 -0.2721409 0.4785254 0.2218446 0.8061704

6 0.1550266 0.7759566 0.3037026 0.0387955 -0.3109364 0.4937598 0.1998196 0.8239993

7 0.1048986 0.4549995 0.1999359 0.0176520 -0.3050212 0.5049305 0.2114158 0.8416513

8 0.1550269 0.7736709 0.1038886 0.0136568 -0.3186780 0.5102829 0.2036268 0.8479574

9 0.1048986 0.4558873 0.0694841 0.0062260 -0.3165899 0.5142170 0.2077098 0.8541834

10 0.1550269 0.7728060 0.0362400 0.0048115 -0.3214013 0.5161012 0.2049610 0.8564092

11 0.1048986 0.4562157 0.0243716 0.0021951 -0.3206649 0.5174875 0.2063996 0.8586042

12 0.1550269 0.7724792 0.0127273 0.0016956 -0.3223605 0.5181513 0.2054302 0.8593892

13 0.1048986 0.4563402 0.0085758 0.0007738 -0.3221009 0.5186398 0.2059372 0.8601630

14 0.1550269 0.7723556 0.0044804 0.0005976 -0.3226985 0.5188738 0.2055955 0.8604397

15 0.1048986 0.4563874 0.0030210 0.0002728 -0.3226070 0.5190460 0.2057742 0.8607124

16 0.1550269 0.7723089 0.0015785 0.0002107 -0.3228177 0.5191284 0.2056537 0.8608100

17 0.1048986 0.4564052 0.0010646 0.0000961 -0.3227854 0.5191891 0.2057167 0.8609061

18 0.1550269 0.7722912 0.0005563 0.0000742 -0.3228597 0.5192182 0.2056742 0.8609405

19 0.1048986 0.4564119 0.0003752 0.0000339 -0.3228483 0.5192396 0.2056964 0.8609744

20 0.1550269 0.7722845 0.0001961 0.0000262 -0.3228745 0.5192498 0.2056815 0.8609865

21 0.1048986 0.4564145 0.0001323 0.0000119 -0.3228705 0.5192574 0.2056893 0.8609985

22 0.1550269 0.7722820 0.0000691 0.0000092 -0.3228797 0.5192610 0.2056840 0.8610027

Получили:

Число итераций: 22

Норма невязки: 0.0000691

Оценка нормы матрицы перехода q: 0.7722820

Последнее приближение: -0.3228797 0.5192610 0.2056840 0.8610027

**МЕТОД ПВР(SOR)**

Вычисление оптимального значения w:

w = 0.1 - число итераций: 109

w = 0.2 - число итераций: 53

w = 0.3 - число итераций: 34

w = 0.4 - число итераций: 25

w = 0.5 - число итераций: 19

w = 0.6 - число итераций: 15

w = 0.7 - число итераций: 12

w = 0.8 - число итераций: 10

w = 0.9 - число итераций: 8

w = 1.0 - число итераций: 6

w = 1.1 - число итераций: 6

w = 1.2 - число итераций: 7

w = 1.3 - число итераций: 8

w = 1.4 - число итераций: 10

w = 1.5 - число итераций: 13

w = 1.6 - число итераций: 16

w = 1.7 - число итераций: 21

w = 1.8 - число итераций: 34

w = 1.9 - число итераций: 68

Минимальное число итераций достигается при w = 1.0

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ w q невязки погр-ти X[1] X[2] X[3] X[4]

1 1.0000000 0.6077434 6.5817253 0.6077434 0.1234568 0.3130511 0.2960888 0.6077434

2 1.0000000 0.5855642 3.6087139 0.3558728 -0.2324160 0.4624096 0.2460274 0.7987803

3 1.0000000 0.2056928 0.6998518 0.0732005 -0.3056165 0.5057739 0.2172686 0.8472134

4 1.0000000 0.1934892 0.1336848 0.0141635 -0.3197800 0.5163460 0.2084980 0.8581706

5 1.0000000 0.1822699 0.0292884 0.0025816 -0.3223615 0.5186772 0.2063042 0.8604621

6 1.0000000 0.1906365 0.0061220 0.0004921 -0.3228024 0.5191550 0.2058120 0.8609115

7 1.0000000 0.2077899 0.0012005 0.0001023 -0.3228718 0.5192470 0.2057097 0.8609945

8 1.0000000 0.1950093 0.0002217 0.0000199 -0.3228814 0.5192637 0.2056898 0.8610089

9 1.0000000 0.1836464 0.0000384 0.0000037 -0.3228825 0.5192665 0.2056861 0.8610112

Получили:

Число итераций: 9

Норма невязки: 0.0000384

Оценка нормы матрицы перехода q: 0.1836464

Последнее приближение: -0.3228825 0.5192665 0.2056861 0.8610112

**МЕТОД СОПРЯЖЕННЫХ ГРАДИЕНТОВ**

Начальное приближение: 1.0000000 2.0000000 3.0000000 4.0000000

Норма Оценка

№ tau q невязки погр-ти X[1] X[2] X[3] X[4]

1 0.1043115 0.4172462 9.5866667 0.4172462 0.1043115 0.2086231 0.3129346 0.4172462

2 0.1550524 1.0723197 2.4799477 0.4474213 -0.3431097 0.4735409 0.2385444 0.8586255

3 0.1515628 0.1052406 0.3286285 0.0470869 -0.3239046 0.5206278 0.2072568 0.8593988

4 0.2098206 0.0342520 0.0089054 0.0016128 -0.3228825 0.5192671 0.2056854 0.8610116

5 0.1225919 0.0000000 0.0000000 0.0000000 -0.3228825 0.5192671 0.2056854 0.8610116

Получили:

Число итераций: 5

Норма невязки: 0.0000000

Оценка нормы матрицы перехода q: 0.0000000

Последнее приближение: -0.3228825 0.5192671 0.2056854 0.8610116

**ПОДВЕДЕМ ИТОГИ:**

**Решение методом LU разложения:**

-0.3228825 0.5192671 0.2056854 0.8610116

Число обусловленности: 6.0837725

**Решение методом простой итерации:**

-0.3228729 0.5192569 0.2056870 0.8609974

Фактическое число итераций: 24

Теоретическое число итераций: 28

Скорость работы метода: 0.033 сек.

**Решение градиентным методом наискорейшего спуска:**

-0.3228797 0.5192610 0.2056840 0.8610027

Фактическое число итераций: 22

Теоретическое число итераций: 28

Скорость работы метода: 0.027 сек.

**Решение методом ПВР:**

-0.3228825 0.5192665 0.2056861 0.8610112

Фактическое число итераций: 9

Теоретическое число итераций: 6

Скорость работы метода: 0.206 сек.

**Решение методом сопряженных градиентов:**

-0.3228825 0.5192671 0.2056854 0.8610116

Фактическое число итераций: 5

Теоретическое число итераций: 12

Скорость работы метода: 0.009 сек.

1. **Краткие выводы**

Для наглядности запишем полученные данные в виде таблиц, тем самым сравним результаты, полученные всеми четырьмя итерационными методами, с решением, полученным прямым методом (LU разложением)

Вариант 3)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Метод: | Фактическое  число итераций | Теоретическая оценка числа итераций | Вектор | | | |
| Прямой (LU) | - |  | -4.2574795 | 26.9193181 | 85.2733485 | -5.4305974 |
| Простой итерации | 1223 | 2272 | -4.2608354 | 26.8432288 | 85.0278527 | -5.4115537 |
| Наискорейшего спуска | 851 | 2272 | -4.2621605 | 26.8482111 | 85.0412799 | -5.4125249 |
| ПВР | 35 | 51 | -4.2762708 | 26.9205984 | 85.2793757 | -5.4312738 |
| Сопряженных градиентов | 5 | 110 | -4.2754795 | 26.9193181 | 85.2733485 | -5.4305974 |

Вариант 6)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Метод: | Фактическое  число итераций | Теоретическая оценка числа итераций |  |  |  |  |
| Прямой (LU) | - |  | -0.3228825 | 0.5192671 | 0.2056854 | 0.8610116 |
| Простой итерации | 24 | 28 | -0.3228729 | 0.5192569 | 0.2056870 | 0.8609974 |
| Наискорейшего спуска | 22 | 28 | -0.3228797 | 0.5192610 | 0.2056840 | 0.8610027 |
| ПВР | 9 | 6 | -0.3228825 | 0.5192665 | 0.2056861 | 0.8610112 |
| Сопряженных градиентов | 5 | 12 | -0.3228825 | 0.5192671 | 0.2056854 | 0.8610116 |

По количеству итераций лучшие результаты показывает метод сопряжённых градиентов, худшие – метод простой итерации.

По вычислительным затратам самым объемным является градиентный метод наискорейшего спуска, самым мало-затратным - метод простой итерации.

Время работы каждого из методов зависит от числа итераций.

1. **Текст программы**

Программа состоит из двух файлов решений «Main.cpp» - исходный файл программы и файл «lab2.cpp» - файл с функцией решения СЛАУ методом LU разложения (лабораторная работа№2), из данного файла нам понадобятся несколько функций. Ниже приведены содержания файлов.

«Main.cpp»

#include <iostream>

#include <fstream>

#include <vector>

#include <iomanip>

#include <limits>

#include <cmath>

#include <algorithm>

#include <string>

using namespace *std*;

// Число строк/столбцов в матрице

int const N = 4;

double const EPS = 0.0001;

typedef vector<vector<double>> myMatrix;

// Метод простой итерации

vector<double> SimpleIterationMethod(myMatrix A, vector<double> b, int &factCountIter, *ofstream* &fout, unsigned int &time)

{

unsigned int start\_time = *clock*();

fout << "МЕТОД ПРОСТОЙ ИТЕРАЦИИ\n\n";

// xPrev соответствует Х(к-1), xNext - Х(к-1), xCur - Х(к)

vector <double> xPrev(N), xCur(N), xNext(N), ax;

double q(0), t(1.8 / NormII(A)), normDiscr; // discrepancy - невязка

// Счётчик итераций

int countIter(0);

fout << "Значения итерационного параметра: " << setprecision(7) << t << endl;

fout << "Начальное приближение: " << b << endl << endl;

fout << *setw*(44) << "Норма " << setw(13) << "Оценка\n";

fout << *setw*(5) << "№" << *setw*(13) << "tau " << *setw*(13) << "q " << *setw*(13)

<<"невязки"<< setw(13) << "погр-ти" << *setw*(13) << setw(13) << "X[1] "

<< setw(13) << "X[2] " << setw(13) << "X[3] "

<< *setw*(13) << "X[4] " << "\n\n";

while (true)

{

ax = A \* xCur;

countIter++;

// Вычисляем х(к+1)

xNext = xCur + (b - ax ) \* t;

// Или каждый элемент

// for (int i = 0; i < N; i++) xNext[i] = xCur[i] + t \* (b[i] - ax[i]);

if (countIter != 1)

q = MinNormVec(xNext - xCur) / MinNormVec(xCur - xPrev);

else q = MinNormVec(xNext);

normDiscr = MinNormVec(ax - b) / MinNormVec(xNext);

fout <<*setw*(5)<<countIter<<*setw*(13)<< t <<*setw*(13)<< q <<*setw*(13)<< normDiscr

<< *setw*(13) << MinNormVec(xNext-xCur) << xNext << "\n";

// Если норма невязки меньше 10^(-4) то прекращаем работу цикла

if (normDiscr < EPS)

break;

// Меняем предыдущее на текущее и текущее на следующее

xPrev = xCur;

xCur = xNext;

}

fout << "\nПолучили: \nЧисло итераций: " << countIter

<< "\nНорма невязки: " << normDiscr << "\n"

<< "Оценка нормы матрицы перехода q: " << q

<< "\nПоследнее приближение: " << xNext << endl;

factCountIter = countIter;

unsigned int end\_time = *clock*();

time = end\_time - start\_time;

return xNext;

}

// Градиентный метод наискорейшего спуска

vector<double> GradientDescentMethod(myMatrix A, vector<double> b, int &factCountIter, *ofstream* &fout, unsigned int &time)

{

unsigned int start\_time = *clock*();

fout << "\n\nГРАДИЕНТНЫЙ МЕТОД НАИСКОРЕЙШЕГО СПУСКА\n\n";

vector <double> xPrev(N), xCur(N), xNext(N), ax, r, ar;

double q(0), t, normDiscr;

int countIter(0);

fout << "Начальное приближение: " << b << endl << endl;

fout << *setw*(44) << "Норма " << setw(13) << "Оценка\n";

fout << *setw*(5) << "№" << *setw*(13) << "tau " << *setw*(13) << "q " << *setw*(13)

<< "невязки" << setw(13) << "погр-ти" << *setw*(13) << setw(13) << "X[1] "

<< setw(13) << "X[2] " << setw(13) << "X[3] "

<< *setw*(13) << "X[4] " << "\n\n";

while (true)

{

countIter++;

ax = A \* xCur;

r = ax - b;

ar = A \* r;

t = (r \* r) / (ar \* r);

xNext = xCur - r \* t;

if (countIter != 1)

q = MinNormVec(xNext - xCur) / MinNormVec(xCur - xPrev);

else q = MinNormVec(xNext);

normDiscr = MinNormVec(ax - b) / MinNormVec(xNext);

fout <<*setw*(5)<<countIter<<*setw*(13)<< t <<*setw*(13)<< q <<*setw*(13)<< normDiscr

<< *setw*(13) << MinNormVec(xNext - xCur) << xNext << "\n";

if (normDiscr < EPS) break;

xPrev = xCur;

xCur = xNext;

}

fout << "Получили: \nЧисло итераций: " << countIter << "\nНорма невязки: "

<< normDiscr << "\n" << "Оценка нормы матрицы перехода q: " << q

<< "\Последнее приближение: " << xNext << endl;

factCountIter = countIter;

unsigned int end\_time = *clock*();

time = end\_time - start\_time;

return xNext;

}

// Вычсление следующей итерации для метода ПВР

vector <double> CalcNextX(myMatrix A, vector<double> b, vector<double> xCur, double w)

{

vector<double> xNext(N);

double sum;

for (int i = 0; i < N; i++)

{

sum = 0;

for (int j = 0; j < i; j++)

sum += A[i][j] \* xNext[j];

for (int j = i + 1; j < N; j++)

sum += A[i][j] \* xCur[j];

xNext[i] = xCur[i] + w\*((b[i] - sum) / A[i][i] - xCur[i]);

}

return xNext;

}

// Поиск оптимального значения w

double wSearch(myMatrix A, vector<double> b, *ofstream* &fout)

{

double const eps = 0.01;

double w(0.1), wOptimal(0.1), s;

int countIter, minCountIter(*INT\_MAX*);

for (w; w < 2; w += 0.1)

{

countIter = 0;

vector<double> xCur(N), xNext(N);

do

{

xCur = xNext;

countIter++;

xNext = CalcNextX(A, b, xCur, w);

} while (MinNormVec(A\*xCur - b) / MinNormVec(xNext)>= eps);

if (countIter < minCountIter)

{

wOptimal = w;

minCountIter = countIter;

}

fout << "w = "<<*setprecision*(1)<< w <<" - число итераций: "<<*countIter*<< endl;

}

fout <<"\nМинимальное число итераций достигается при w = "<<wOptimal <<endl << endl;

return wOptimal;

}

// Метол ПВР

vector<double> MethodSOR(myMatrix A, vector<double> b, int &factCountIter, *ofstream* &fout, unsigned int &time)

{

unsigned int start\_time = *clock*();

fout << "\n\nМЕТОД ПВР(SOR)\n\n";

vector <double> xPrev(N), xCur(N), xNext(N), ax;

double q(0), s, normDiscr, w = wSearch(A, b, fout); // discrepancy - невязка

int countIter(0);

fout << "Начальное приближение: " << b << endl << endl;

fout << *setw*(44) << "Норма " << setw(13) << "Оценка\n";

fout << *setw*(5) << "№" << *setw*(13) << "w " << *setw*(13) << "q " << *setw*(13)

<< "невязки" << setw(13) << "погр-ти" << *setw*(13) << setw(13) << "X[1] "

<< setw(13) << "X[2] " << setw(13) << "X[3] "

<< *setw*(13) << "X[4] " << "\n\n";

while (true)

{

countIter++;

xNext = CalcNextX(A, b, xCur, w);

ax = A \* xCur;

if (countIter > 1)

q = MinNormVec(xNext - xCur) / MinNormVec(xCur - xPrev);

else q = MinNormVec(xNext - xCur);

normDiscr = MinNormVec(ax - b)/MinNormVec(xNext);

fout <<*setw*(5)<<countIter<<*setw*(13)<< w <<*setw*(13)<< q <<*setw*(13)<< normDiscr

<< *setw*(13) << MinNormVec(xNext - xCur) << xNext << "\n";

if (normDiscr < EPS) break;

xPrev = xCur;

xCur = xNext;

}

fout << "Получили: \nЧисло итераций: " << countIter << "\nНорма невязки: "

<< normDiscr << "\n" << "Оценка нормы матрицы перехода q: " << q

<< "\Последнее приближение: " << xNext << endl;

factCountIter = countIter;

unsigned int end\_time = *clock*();

time = end\_time - start\_time;

return xNext;

}

// Метод сопряженных градиентов

vector<double> ConjugateGradientMethod(myMatrix A, vector<double> b, int &factCountIter, *ofstream* &fout, unsigned int &time)

{

unsigned int start\_time = *clock*();

fout << "\n\nМЕТОД СОПРЯЖЕННЫХ ГРАДИЕНТОВ\n\n";

vector <double> xPrev(N), xCur(N), xNext(N), ax, r, rPrev, ar;

double q(0), tCur, tNext(0), normDiscr, a(1); // discrepancy - невязка

int countIter(0);

fout << "Начальное приближение: " << b << endl << endl;

fout << *setw*(44) << "Норма " << setw(13) << "Оценка\n";

fout << *setw*(5) << "№" << *setw*(13) << "tau " << *setw*(13) << "q " << *setw*(13)

<< "невязки" << setw(13) << "погр-ти" << *setw*(13) << setw(13) << "X[1] "

<< setw(13) << "X[2] " << setw(13) << "X[3] "

<< *setw*(13) << "X[4] " << "\n\n";

while (true)

{

countIter++;

ax = A \* xCur;

r = ax - b; //вычисляем вектор невязки

tCur = tNext; //переопред t для вычисления альфа

ar = A \* r;

tNext = (r \* r) / (ar \* r);

if (countIter > 1)

a = 1 / (1 - (tNext / (tCur\*a))\*((r \* r) / (rPrev \* rPrev)));

xNext = xCur \* a + xPrev \* (1 - a) - r \* tNext\*a;

if (countIter != 1)

q = MinNormVec(xNext - xCur) / MinNormVec(xCur - xPrev);

else q = MinNormVec(xNext);

normDiscr = MinNormVec(A \* xCur - b) / MinNormVec(xNext);

fout <<*setw*(5)<<countIter<<*setw*(13)<<tNext<<*setw*(13)<<q<<*setw*(13)<< normDiscr

<< *setw*(13) << MinNormVec(xNext - xCur) << xNext << "\n";

rPrev = r;

xPrev = xCur;

xCur = xNext;

if (normDiscr < EPS) break;

}

fout << "Получили: \nЧисло итераций: " << countIter << "\nНорма невязки: "

<< normDiscr << "\n" << "Оценка нормы матрицы перехода q: " << q

<< "\Последнее приближение: " << xNext << endl;

factCountIter = countIter;

unsigned int end\_time = *clock*();

time = end\_time - start\_time;

return xNext;

}

// Основная ф-я

int main()

{

*setlocale*(*LC\_ALL*, "Russian");

// Номер набора

int num = 6;

// Файл для записи

*ofstream* fout;

// Файл для считывания

*ifstream* fin;

// A - исх. матрица

myMatrix A, L, U, P(CreateMatrixP());

// Исходный вектор b и вектор решений х

vector<double> b, x;

// Открываем файл для считывания данных

fin.*open*("input" + *to\_string*(num) + ".txt");

// Считываем матрицу целиком

fin >> A;

// Считываем вектор целиком

fin >> b;

// Ранг матрицы A (предполагаем, что он равен 4-м)

int rang = N;

// Закрываем файл для считывания

fin.*close*();

//fout.open("output.txt");

fout.*open*("output" + *to\_string*(num) + ".txt");

// Выведем матрицу и вектор

fout << "Вектор b: \n" << *b* << endl << endl;

fout << "Исходная матрица А: \n" << A << endl;

// Норма матрицы

fout << "Норма матрицы А: " << *NormII*(A) << endl << endl;

// Фактическое число итераций в каждом из методов

int mFactSIM, mFactGDM, mFactSOR, mFactCGM;

// Время работы каждого из методов

unsigned int timeSIM, timeGDM, timeSOR, timeCGM;

// Метод простой итерации

auto xSIM = SimpleIterationMethod(A, b, mFactSIM, fout, timeSIM);

// Градиентный метод наискорейшего спуска

auto xGDM = GradientDescentMethod(A, b, mFactGDM, fout, timeGDM);

//Метод ПВР

auto xSOR = MethodSOR(A, b, mFactSOR, fout, timeSOR);

// Метод сопряженных градиентов

auto xCGM = ConjugateGradientMethod(A, b, mFactCGM, fout, timeCGM);

// LU разложение

U = CreateMatrixU(A, P, rang);

L = CreateMatrixL(A, U);

// Метод LU разложения

auto xLU = SolveX(b, P, L, U);

// Число обусловленности (для сравнения числа итераций)

double cond(NormII(A)\*NormII(ReverseMatrix(P, L, U)));

//Теоретическое исло итераций по каждому из методов

int mTeorSIM(round(0.5 \* cond \* *log*(1 / EPS))),

mTeorGDM(round(0.5 \* cond \* *log*(1 / EPS))),

mTeorSOR(round(0.25 \* *sqrt*(cond) \* *log*(1 / EPS))),

mTeorCGM(round(*sqrt*(cond) \* *log*(2 / EPS) \* 0.5));

fout << "\n\nПОДВЕДЕМ ИТОГИ: \n\n";

fout << "Решение методом LU разложения: \n" << xLU << endl << endl;

fout << "\nЧисло обусловленности: " << cond << endl;

fout << "Решение методом простой итерации: \n" << xSIM << endl <<

"Фактическое число итераций: " << mFactSIM <<

"\nТеоретическое число итераций: " << mTeorSIM <<

"\nСкорость работы метода: " << timeSIM / 1000.0 << " сек.\n\n";

fout << "Решение градиентным методом наискорейшего спуска: \n" << xGDM << endl <<

"Фактическое число итераций: " << mFactGDM <<

"\nТеоретическое число итераций: " << mTeorGDM <<

"\nСкорость работы метода: " << timeGDM / 1000.0 << " сек.\n\n";

fout << "Решение методом ПВР: \n" << xSOR << endl <<

"Фактическое число итераций: " << mFactSOR <<

"\nТеоретическое число итераций: " << mTeorSOR <<

"\nСкорость работы метода: " << timeSOR / 1000.0 << " сек.\n\n";

fout << "Решение методом сопряженных градиентов: \n" << xCGM << endl <<

"Фактическое число итераций: " << mFactCGM <<

"\nТеоретическое число итераций: " << mTeorCGM <<

"\nСкорость работы метода: " << timeCGM / 1000.0 << " сек.\n\n";

fout.*close*();

//system("pause");

return 0;

}

«Lab2.cpp»

#include <iostream>

#include <fstream>

#include <vector>

#include <iomanip>

#include <limits>

#include <cmath>

#include <algorithm>

#include <numeric>

#include <string>

#include <functional>

#include "linalg.h"

using namespace *std*;

int const N = 4;

typedef vector<vector<double>> myMatrix;

// Перегрузка оператор >> для вектора

*istream* &operator >> (*istream* &in, vector<double> &v)

{

double num;

for (int i = 0; i < N; i++)

{

in >> num;

v.*push\_back*(num);

}

return in;

}

// Перегрузка оператор << для вектора

*ostream* &operator << (*ostream* &out, vector<double> &v)

{

for (int i = 0; i < N; i++)

// 8 знаков после запятой и ширина столбца 15 символов

out << *fixed* << *setprecision*(7) << *setw*(13) << v[i];

//out << endl;

return out;

}

// Умножение вектора на вектор (переопределение оператора \*)

double operator \* (vector<double> v1, vector<double> v2)

{

double sum(0);

for (int i = 0; i < N; i++)

sum += v1[i] \* v2[i];

return sum;

}

// Умножение вектора на число (переопределение оператора \*)

vector<double> operator \* (vector<double> v, double num)

{

vector<double> res;

for (int i = 0; i < N; i++)

res.*push\_back*(v[i] \* num);

return res;

}

// Деление вектора на число (переопределение оператора /)

vector<double> operator / (vector<double> v, double num)

{

vector<double> res;

for (int i = 0; i < N; i++)

res.*push\_back*(v[i] / num);

return res;

}

// Разность 2-х векторов поэлементно (переопределение оператора -)

vector<double> operator - (vector<double> v1, vector<double> v2)

{

vector<double> res;

for (int i = 0; i < N; i++)

res.*push\_back*(v1[i] - v2[i]);

return res;

}

// Сложение 2-х векторов поэлементно (переопределение оператора +)

vector<double> operator + (vector<double> v1, vector<double> v2)

{

vector<double> res;

for (int i = 0; i < N; i++)

res.*push\_back*(v1[i] + v2[i]);

return res;

}

// Создаёт пустую матрицу

myMatrix EmptyMatrix()

{

vector<double> v(N);

myMatrix emp;

for (int i = 0; i < N; i++)

emp.*push\_back*(v);

return emp;

}

// Перегрузка оператора >> для матрицы

*istream* &operator >> (*istream* &in, myMatrix &v)

{

vector<double> str;

for (int i = 0; i < N; i++)

{

in >> str;

v.*push\_back*(str);

str.*clear*();

}

return in;

}

// Перегрузка оператора << для матрицы

*ostream* &operator << (*ostream* &out, myMatrix &v)

{

for (int i = 0; i < N; i++)

// 8 знаков после запятой и ширина столбца 15 символов

out << *fixed* << *setprecision*(7) << *setw*(13) << v[i] << *endl*;

return out;

}

// Перегрузка оператора \* для перемножения двух матриц

myMatrix operator \* (myMatrix &M1, myMatrix &M2)

{

myMatrix res = EmptyMatrix();

for (int i = 0; i < M1.*size*(); i++)

for (int j = 0; j < M1[0].*size*(); j++)

for (int k = 0; k < M1[0].*size*(); k++)

res[i][j] += M1[i][k] \* M2[k][j];

return res;

}

// Перегрузка оператора \* для умножения матрицы на вектор

vector<double> operator \* (myMatrix &M, vector<double> &v)

{

vector<double> res(N);

for (int i = 0; i < N; i++)

for (int j = 0; j < N; j++)

res[i] += M[i][j]\*v[j];

return res;

}

// Перегрузка оператора - для вычитания двух матриц

myMatrix operator - (myMatrix &M1, myMatrix &M2)

{

myMatrix res = EmptyMatrix();

for (int i = 0; i < N; i++)

for (int j = 0; j < N; j++)

res[i][j] += M1[i][j] - M2[i][j

];

return res;

}

// Перегрузка оператора + для сложения двух матриц

myMatrix operator + (myMatrix &M1, myMatrix &M2)

{

myMatrix res = EmptyMatrix();

for (int i = 0; i < N i++)

for (int j = 0; j < N; j++)

res[i][j] += M1[i][j] + M2[i][j];

return res;

}

// Перегрузка оператора \* для умножения матрицы на число

myMatrix operator \* (myMatrix &M1, double &d)

{

myMatrix res = EmptyMatrix();

for (int i = 0; i < M1.*size*(); i++)

for (int j = 0; j < M1[0].*size*(); j++)

res[i][j] += M1[i][j] \* d;

return res;

}

// Функция поиска индекса строки в которой лежит максимальный элемент нужного столбцы

int IndexMaxNumInColumn(myMatrix M, int columnIndex)

{

int ind = columnIndex;

for (int i = columnIndex; i < N; i++)

if (*fabs*(M[i][columnIndex]) > *fabs*(M[ind][columnIndex]))

ind = i;

if (M[ind][columnIndex] == 0) // Получили 0 на диагонали

return -1;

return ind;

}

// Ф-я, которая меняет местами строки

void Swap(myMatrix &M, int index1, int index2)

{

auto tmp = M[index1];

M[index1] = M[index2];

M[index2] = tmp;

}

// Создаём матрицу U

myMatrix CreateMatrixU(myMatrix &A, myMatrix &P, int &rang)

{

auto U = A;

int ind;

// Пробегаем по всем строкам

for (int i = 0; i < N; i++)

{

// Ищем индекс максимального элемента в столбце

ind = IndexMaxNumInColumn(U, i);

// Значит весь столбец (начиная со строки i и до N) состоит из 0, а значит ранг равен пройденному числу строк

if (ind == -1)

{

rang = i;

return U;

}

// Если найденный индекс не явл. индексом тек. строки, то меняем строки

if (ind != i)

{

Swap(U, i, ind);

Swap(A, i, ind);

Swap(P, i, ind);

}

// Диагональный элемент делаем 1

U[i] = U[i] / U[i][i];

// Занулляем всё, что под диагональю

for (int j = i + 1; j < N; j++)

U[j] = U[j] - U[i] \* U[j][i];

}

return U;

}

// Создаём матрицу L

myMatrix CreateMatrixL(myMatrix A, myMatrix U)

{

auto L = EmptyMatrix();

for (int i = 0; i < N; i++)

{

for (int j = 0; j <= i; j++)

{

L[i][j] = A[i][j];

for (int k = 0; k < j; k++)

L[i][j] -= L[i][k] \* U[k][j];

}

}

return L;

}

// Вычисление определителя

double Determinant(myMatrix L)

{

double det = 1;

for (int i = 0; i < N; i++)

det \*= L[i][i];

return det;

}

// Создаем матрицу перестановок P

myMatrix CreateMatrixP()

{

auto P = EmptyMatrix();

for (int i = 0; i < N; i++)

P[i][i] = 1;

return P;

}

// Решаем систему, находим вектор X

vector<double> SolveX(vector<double> &b, myMatrix P, myMatrix L, myMatrix U)

{

// Делаем перестановку элеметов вектора b в соответствии с матрицей перестановок

auto b1 = P \* b;

// Решение уравнение Ly=b (Находим вектор y)

vector<double> y;

for (int i = 0; i < N; i++)

{

// Вычитаем из правой части все уже вычесленные значения y, домноженнные на коэффициенты

for (int j = 0; j < i; j++)

b1[i] -= L[i][j] \* y[j];

// Делим полученную правую часть на коэффициент при даигонали и ккладуём в вектор y

y.*push\_back*(b1[i] / L[i][i]);

}

// Решение уравнение Ux=y (находим вектор x)

// Так как на диагоналях стоят 1, то делить на коэффициент не нужно, поэтому присвоим

auto x = y;

for (int i = N - 1; i >= 0; i--)

for (int j = N - 1; j > i; j--)

x[i] -= U[i][j] \* x[j];

return x;

}

// Находим вектор правых частей

vector<double> SolveB(vector<double> x, myMatrix A)

{

vector<double> b(N);

for (int i = 0; i < N; i++)

for (int j = 0; j < N; j++)

b[i] += A[i][j] \* x[j];

return b;

}

// Транспонирование матрицы

myMatrix TransposeMatrix(myMatrix M)

{

myMatrix res = M;

for (int i = 0; i < N; i++)

for (int j = i + 1; j < N; j++)

{

double tmp = res[i][j];

res[i][j] = res[j][i];

res[j][i] = tmp;

}

return res;

}

// Создание обратной матрицы

myMatrix ReverseMatrix(myMatrix P, myMatrix L, myMatrix U)

{

myMatrix A\_ = EmptyMatrix();

// Единичнвя матрица

myMatrix E = CreateMatrixP();

for (int i = 0; i < N; i++)

A\_[i] = SolveX(E[i], P, L, U);

return TransposeMatrix(A\_);

}

// Максимальная сумма столбцов/строк в матрице

double MaxSumRowOrColumn(myMatrix A, int numNorm)

{

double max(0), sum(0);

for (int i = 0; i < A.*size*(); i++)

{

for (int j = 0; j < A.*size*(); j++)

if (numNorm == 1)

sum += *fabs*(A[i][j]);

else

sum += *fabs*(A[j][i]);

if (sum > max)

max = sum;

sum = 0;

}

return max;

}

// норма матрицы I

double NormI(myMatrix A)

{

return MaxSumRowOrColumn(A, 1);

}

// норма матрицы II

double NormII(myMatrix A)

{

return MaxSumRowOrColumn(A, 2);

}

// норма матрицы III

double NormIII(myMatrix A)

{

auto At = TransposeMatrix(A);

auto AtA = At \* A;

alglib::real\_2d\_array a, vl, vr;

a.setlength(N, N);

alglib::real\_1d\_array wl, wi;

wl.setlength(N); wi.setlength(N);

for (int i = 0; i < N; i++)

for (int j = 0; j < N; j++)

a[i][j] = AtA[j][i];

rmatrixevd(a, N, 0, wl, wi, vl, vr);

double maxVal(*DBL\_MIN*);

for (int i = 0; i < N; i++)

if (*fabs*(wl[i]) > maxVal)

maxVal = *fabs*(wl[i]);

return maxVal;

}

// 1-я норма вектора

double NormVecI(vector <double> v)

{

double m = 0;

for (int i = 0; i < N; i++)

m = m < *abs*(v[i]) ? *abs*(v[i]) : m;

return m;

}

// 2-я норма вектора

double NormVecII(vector <double> v)

{

double sum = 0;

for (int i = 0; i < N; i++)

sum += *fabs*(v[i]);

return sum;

}

// 3-я норма вектора

double NormVecIII(vector <double> v)

{

double sum = 0;

for (int i = 0; i < N; i++)

sum += v[i] \* v[i];

return *sqrt*(sum);

}

// Минимальная из норм вектора

double MinNormVec(vector<double> v)

{

double N1 = NormVecI(v);

double N2 = NormVecII(v);

double N3 = NormVecIII(v);

if (N1 < N2) {

if (N1 < N3)

return N1;

else

return N3;

}else

return N2;

}