

Chapter 04.08

Gauss-Seidel Method

After reading this chapter, you should be able to:

1. solve a set of equations using the Gauss-Seidel method,
2. recognize the advantages and pitfalls of the Gauss-Seidel method, and
3. determine under what conditions the Gauss-Seidel method always converges.

Why do we need another method to solve a set of simultaneous linear equations?

In certain cases, such as when a system of equations is large, iterative methods of solving equations are more advantageous. Elimination methods, such as Gaussian elimination, are prone to large round-off errors for a large set of equations. Iterative methods, such as the Gauss-Seidel method, give the user control of the round-off error. Also, if the physics of the problem are well known, initial guesses needed in iterative methods can be made more judiciously leading to faster convergence.

What is the algorithm for the Gauss-Seidel method? Given a general set of n equations and n unknowns, we have

$$\begin{aligned}a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \dots + a_{1n}x_n &= c_1 \\a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \dots + a_{2n}x_n &= c_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ a_{n1}x_1 + a_{n2}x_2 + a_{n3}x_3 + \dots + a_{nn}x_n &= c_n\end{aligned}$$

If the diagonal elements are non-zero, each equation is rewritten for the corresponding unknown, that is, the first equation is rewritten with x_1 on the left hand side, the second equation is rewritten with x_2 on the left hand side and so on as follows

$$\begin{aligned}
 x_2 &= \frac{c_2 - a_{21}x_1 - a_{23}x_3 \cdots \cdots - a_{2n}x_n}{a_{22}} \\
 &\vdots \\
 &\vdots \\
 x_{n-1} &= \frac{c_{n-1} - a_{n-1,1}x_1 - a_{n-1,2}x_2 \cdots \cdots - a_{n-1,n-2}x_{n-2} - a_{n-1,n}x_n}{a_{n-1,n-1}} \\
 x_n &= \frac{c_n - a_{n1}x_1 - a_{n2}x_2 - \cdots \cdots - a_{n,n-1}x_{n-1}}{a_{nn}}
 \end{aligned}$$

These equations can be rewritten in a summation form as

$$\begin{aligned}
 x_1 &= \frac{c_1 - \sum_{\substack{j=1 \\ j \neq 1}}^n a_{1j}x_j}{a_{11}} \\
 x_2 &= \frac{c_2 - \sum_{\substack{j=1 \\ j \neq 2}}^n a_{2j}x_j}{a_{22}} \\
 &\cdot \\
 &\cdot \\
 &\cdot \\
 x_{n-1} &= \frac{c_{n-1} - \sum_{\substack{j=1 \\ j \neq n-1}}^n a_{n-1,j}x_j}{a_{n-1,n-1}} \\
 x_n &= \frac{c_n - \sum_{\substack{j=1 \\ j \neq n}}^n a_{nj}x_j}{a_{nn}}
 \end{aligned}$$

Hence for any row i ,

$$x_i = \frac{c_i - \sum_{\substack{j=1 \\ j \neq i}}^n a_{ij}x_j}{a_{ii}}, i = 1, 2, \dots, n.$$

Now to find x_i 's, one assumes an initial guess for the x_i 's and then uses the rewritten equations to calculate the new estimates. Remember, one always uses the most recent estimates to calculate the next estimates, x_i . At the end of each iteration, one calculates the absolute relative approximate error for each x_i as

$$\left| \epsilon_a \right|_i = \left| \frac{x_i^{\text{new}} - x_i^{\text{old}}}{x_i^{\text{new}}} \right| \times 100$$

where x_i^{new} is the recently obtained value of x_i , and x_i^{old} is the previous value of x_i .

When the absolute relative approximate error for each x_i is less than the pre-specified tolerance, the iterations are stopped.

Example 1

Three-phase loads are common in AC systems. When the system is balanced the analysis can be simplified to a single equivalent circuit model. However, when it is unbalanced the only practical solution involves the solution of simultaneous linear equations. In one model the following equations need to be solved.

$$\begin{bmatrix} 0.7460 & -0.4516 & 0.0100 & -0.0080 & 0.0100 & -0.0080 \\ 0.4516 & 0.7460 & 0.0080 & 0.0100 & 0.0080 & 0.0100 \\ 0.0100 & -0.0080 & 0.7787 & -0.5205 & 0.0100 & -0.0080 \\ 0.0080 & 0.0100 & 0.5205 & 0.7787 & 0.0080 & 0.0100 \\ 0.0100 & -0.0080 & 0.0100 & -0.0080 & 0.8080 & -0.6040 \\ 0.0080 & 0.0100 & 0.0080 & 0.0100 & 0.6040 & 0.8080 \end{bmatrix} \begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 120 \\ 0.000 \\ -60.00 \\ -103.9 \\ -60.00 \\ 103.9 \end{bmatrix}$$

Find the values of I_{ar} , I_{ai} , I_{br} , I_{bi} , I_{cr} , and I_{ci} using the Gauss-Seidel method. Use

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 20 \\ 20 \\ 20 \\ 20 \\ 20 \\ 20 \end{bmatrix}$$

as the initial guess and conduct two iterations.

Solution

Rewriting the equations gives

$$\begin{aligned} I_{ar} &= \frac{120 - (-0.4516)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7460} \\ I_{ai} &= \frac{0.000 - 0.4516I_{ar} - 0.0080I_{br} - 0.0100I_{bi} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7460} \\ I_{br} &= \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - (-0.5205)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7787} \\ I_{bi} &= \frac{-103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.5205I_{br} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7787} \\ I_{cr} &= \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - (-0.6040)I_{ci}}{0.8080} \\ I_{ci} &= \frac{103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.0080I_{br} - 0.0100I_{bi} - 0.6040I_{cr}}{0.8080} \end{aligned}$$

Iteration #1

Given the initial guess of the solution vector as

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 20 \\ 20 \\ 20 \\ 20 \\ 20 \\ 20 \end{bmatrix}$$

Substituting the guess values into the first equation

$$\begin{aligned} I_{ar} &= \frac{120 - (-0.4516)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7460} \\ &= 172.86 \end{aligned}$$

Substituting the new value of I_{ar} and the remaining guess values into the second equation

$$\begin{aligned} I_{ai} &= \frac{0.000 - 0.4516I_{ar} - 0.0080I_{br} - 0.0100I_{bi} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7460} \\ &= -105.61 \end{aligned}$$

Substituting the new values of I_{ar} , I_{ai} , and the remaining guess values into the third equation

$$\begin{aligned} I_{br} &= \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - (-0.5205)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7787} \\ &= -67.039 \end{aligned}$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , and the remaining guess values into the fourth equation

$$\begin{aligned} I_{bi} &= \frac{-103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.5205I_{br} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7787} \\ &= -89.499 \end{aligned}$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , I_{bi} , and the remaining guess values into the fifth equation

$$\begin{aligned} I_{cr} &= \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - (-0.6040)I_{ci}}{0.8080} \\ &= -62.548 \end{aligned}$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , I_{bi} , I_{cr} , and the remaining guess value into the sixth equation

$$\begin{aligned} I_{ci} &= \frac{103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.0080I_{br} - 0.0100I_{bi} - 0.6040I_{cr}}{0.8080} \\ &= 176.71 \end{aligned}$$

The absolute relative approximate error for each I then is

$$\begin{aligned} |\epsilon_a|_1 &= \left| \frac{172.86 - 20}{172.86} \right| \times 100 \\ &= 88.430\% \end{aligned}$$

$$|\epsilon_a|_2 = \left| \frac{-105.61 - 20}{-105.61} \right| \times 100$$

$$= 118.94\%$$

$$|\epsilon_a|_3 = \left| \frac{-67.039 - 20}{-67.039} \right| \times 100$$

$$= 129.83\%$$

$$|\epsilon_a|_4 = \left| \frac{-89.499 - 20}{-89.499} \right| \times 100$$

$$= 122.35\%$$

$$|\epsilon_a|_5 = \left| \frac{-62.548 - 20}{-62.548} \right| \times 100$$

$$= 131.98\%$$

$$|\epsilon_a|_6 = \left| \frac{176.71 - 20}{176.71} \right| \times 100$$

$$= 88.682\%$$

At the end of the first iteration, the estimate of the solution vector is

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 172.86 \\ -105.61 \\ -67.039 \\ -89.499 \\ -62.548 \\ 176.71 \end{bmatrix}$$

and the maximum absolute relative approximate error is 131.98% .

Iteration #2

The estimate of the solution vector at the end of Iteration #1 is

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 172.86 \\ -105.61 \\ -67.039 \\ -89.499 \\ -62.548 \\ 176.71 \end{bmatrix}$$

Substituting the values from Iteration #1 into the first equation

$$I_{ar} = \frac{120 - (-0.4516)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7460}$$

$$= 99.600$$

Substituting the new value of I_{ar} and the remaining values from Iteration #1 into the second equation

$$I_{ai} = \frac{0.000 - 0.4516I_{ar} - 0.0080I_{br} - 0.0100I_{bi} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7460}$$

$$= -60.073$$

Substituting the new values of I_{ar} , I_{ai} , and the remaining values from Iteration #1 into the third equation

$$I_{br} = \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - (-0.5205)I_{bi} - 0.0100I_{cr} - (-0.0080)I_{ci}}{0.7787}$$

$$= -136.15$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , and the remaining values from Iteration #1 into the fourth equation

$$I_{bi} = \frac{-103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.5205I_{br} - 0.0080I_{cr} - 0.0100I_{ci}}{0.7787}$$

$$= -44.299$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , I_{bi} , and the remaining values from Iteration #1 into the fifth equation

$$I_{cr} = \frac{-60.00 - 0.0100I_{ar} - (-0.0080)I_{ai} - 0.0100I_{br} - (-0.0080)I_{bi} - (-0.6040)I_{ci}}{0.8080}$$

$$= 57.259$$

Substituting the new values of I_{ar} , I_{ai} , I_{br} , I_{bi} , I_{cr} , and the remaining value from Iteration #1 into the sixth equation

$$I_{ci} = \frac{103.9 - 0.0080I_{ar} - 0.0100I_{ai} - 0.0080I_{br} - 0.0100I_{bi} - 0.6040I_{cr}}{0.8080}$$

$$= 87.441$$

The absolute relative approximate error for each I then is

$$|\epsilon_a|_1 = \left| \frac{99.600 - 172.86}{99.600} \right| \times 100$$

$$= 73.552\%$$

$$|\epsilon_a|_2 = \left| \frac{-60.073 - (-105.61)}{-60.073} \right| \times 100$$

$$= 75.796\%$$

$$|\epsilon_a|_3 = \left| \frac{-136.35 - (-67.039)}{-136.35} \right| \times 100$$

$$= 50.762\%$$

$$|\epsilon_a|_4 = \left| \frac{-44.299 - (-89.499)}{-44.299} \right| \times 100$$

$$= 102.03\%$$

$$\begin{aligned}
 |\epsilon_a|_5 &= \left| \frac{57.259 - (-62.548)}{57.259} \right| \times 100 \\
 &= 209.24\% \\
 |\epsilon_a|_6 &= \left| \frac{87.441 - 176.71}{87.441} \right| \times 100 \\
 &= 102.09\%
 \end{aligned}$$

At the end of the second iteration, the estimate of the solution vector is

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 99.600 \\ -60.073 \\ -136.15 \\ -44.299 \\ 57.259 \\ 87.441 \end{bmatrix}$$

and the maximum absolute relative approximate error is 141.4087% .

Conducting more iterations gives the following values for the solution vector and the corresponding absolute relative approximate errors.

Iteration	I_{ar}	I_{ai}	I_{br}	I_{bi}	I_{cr}	I_{ci}
1	172.86	-105.61	-67.039	-89.499	-62.548	176.71
2	99.600	-60.073	-136.15	-44.299	57.259	87.441
3	126.01	-76.015	-108.90	-62.667	-10.478	137.97
4	117.25	-70.707	-119.62	-55.432	27.658	109.45
5	119.87	-72.301	-115.62	-58.141	6.2513	125.49
6	119.28	-71.936	-116.98	-57.216	18.241	116.53

Iteration	$ \epsilon_a _1$ %	$ \epsilon_a _2$ %	$ \epsilon_a _3$ %	$ \epsilon_a _4$ %	$ \epsilon_a _5$ %	$ \epsilon_a _6$ %
1	88.430	118.94	129.83	122.35	131.98	88.682
2	73.552	75.796	50.762	102.03	209.24	102.09
3	20.960	20.972	25.027	29.311	646.45	36.623
4	7.4738	7.5067	8.9631	13.053	137.89	26.001
5	2.1840	2.2048	3.4633	4.6595	342.43	12.742
6	0.49408	0.50789	1.1629	1.6170	65.729	7.6884

After six iterations, the absolute relative approximate errors are decreasing, but are still high. Allowing for more iteration, the relative approximate errors decrease significantly.

Iteration	I_{ar}	I_{ai}	I_{br}	I_{bi}	I_{cr}	I_{ci}
32	119.33	-71.973	-116.66	-57.432	13.940	119.74
33	119.33	-71.973	-116.66	-57.432	13.940	119.74

Iteration	$ \epsilon_a _1$ %	$ \epsilon_a _2$ %	$ \epsilon_a _3$ %	$ \epsilon_a _4$ %	$ \epsilon_a _5$ %	$ \epsilon_a _6$ %
32	3.0666×10^{-7}	3.0047×10^{-7}	4.2389×10^{-7}	5.7116×10^{-7}	2.0941×10^{-5}	1.8238×10^{-6}
33	1.7062×10^{-7}	1.6718×10^{-7}	2.3601×10^{-7}	3.1801×10^{-7}	1.1647×10^{-5}	1.0144×10^{-6}

After 33 iterations, the solution vector is

$$\begin{bmatrix} I_{ar} \\ I_{ai} \\ I_{br} \\ I_{bi} \\ I_{cr} \\ I_{ci} \end{bmatrix} = \begin{bmatrix} 119.33 \\ -71.973 \\ -116.66 \\ -57.432 \\ 13.940 \\ 119.74 \end{bmatrix}$$

The maximum absolute relative approximate error is 1.1647×10^{-5} % .

Example 2

Find the solution to the following system of equations using the Gauss-Seidel method.

$$12x_1 + 3x_2 - 5x_3 = 1$$

$$x_1 + 5x_2 + 3x_3 = 28$$

$$3x_1 + 7x_2 + 13x_3 = 76$$

Use

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

as the initial guess and conduct two iterations.

Solution

The coefficient matrix

$$[A] = \begin{bmatrix} 12 & 3 & -5 \\ 1 & 5 & 3 \\ 3 & 7 & 13 \end{bmatrix}$$

is diagonally dominant as

$$|a_{11}| = |12| = 12 \geq |a_{12}| + |a_{13}| = |3| + |-5| = 8$$

$$|a_{22}| = |5| = 5 \geq |a_{21}| + |a_{23}| = |1| + |3| = 4$$

$$|a_{33}| = |13| = 13 \geq |a_{31}| + |a_{32}| = |3| + |7| = 10$$

and the inequality is strictly greater than for at least one row. Hence, the solution should converge using the Gauss-Seidel method.

Rewriting the equations, we get

$$x_1 = \frac{1 - 3x_2 + 5x_3}{12}$$

$$x_2 = \frac{28 - x_1 - 3x_3}{5}$$

$$x_3 = \frac{76 - 3x_1 - 7x_2}{13}$$

Assuming an initial guess of

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

Iteration #1

$$x_1 = \frac{1 - 3(0) + 5(1)}{12}$$

$$= 0.50000$$

$$x_2 = \frac{28 - (0.50000) - 3(1)}{5}$$

$$= 4.9000$$

$$x_3 = \frac{76 - 3(0.50000) - 7(4.9000)}{13}$$

$$= 3.0923$$

The absolute relative approximate error at the end of the first iteration is

$$|\epsilon_{a1}| = \left| \frac{0.50000 - 1}{0.50000} \right| \times 100$$

$$= 100.000\%$$

$$|\epsilon_{a2}| = \left| \frac{4.9000 - 0}{4.9000} \right| \times 100$$

$$= 100.000\%$$

$$|\epsilon_{a3}| = \left| \frac{3.0923 - 1}{3.0923} \right| \times 100$$

$$= 67.662\%$$

The maximum absolute relative approximate error is 100.000%

Iteration #2

$$x_1 = \frac{1 - 3(4.9000) + 5(3.0923)}{12}$$

$$= 0.14679$$

$$x_2 = \frac{28 - (0.14679) - 3(3.0923)}{5}$$

$$= 3.7153$$

$$x_3 = \frac{76 - 3(0.14679) - 7(3.7153)}{13}$$

$$= 3.8118$$

At the end of second iteration, the absolute relative approximate error is

$$\begin{aligned}
 |\epsilon_a|_1 &= \left| \frac{0.14679 - 0.50000}{0.14679} \right| \times 100 \\
 &= 240.61\% \\
 |\epsilon_a|_2 &= \left| \frac{3.7153 - 4.9000}{3.7153} \right| \times 100 \\
 &= 31.889\% \\
 |\epsilon_a|_3 &= \left| \frac{3.8118 - 3.0923}{3.8118} \right| \times 100 \\
 &= 18.874\%
 \end{aligned}$$

The maximum absolute relative approximate error is 240.61%. This is greater than the value of 100.00% we obtained in the first iteration. Is the solution diverging? No, as you conduct more iterations, the solution converges as follows.

Iteration	x_1	$ \epsilon_a _1$ %	x_2	$ \epsilon_a _2$ %	x_3	$ \epsilon_a _3$ %
1	0.50000	100.00	4.9000	100.00	3.0923	67.662
2	0.14679	240.61	3.7153	31.889	3.8118	18.874
3	0.74275	80.236	3.1644	17.408	3.9708	4.0064
4	0.94675	21.546	3.0281	4.4996	3.9971	0.65772
5	0.99177	4.5391	3.0034	0.82499	4.0001	0.074383
6	0.99919	0.74307	3.0001	0.10856	4.0001	0.00101

This is close to the exact solution vector of

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 3 \\ 4 \end{bmatrix}$$

Example 3

Given the system of equations

$$3x_1 + 7x_2 + 13x_3 = 76$$

$$x_1 + 5x_2 + 3x_3 = 28$$

$$12x_1 + 3x_2 - 5x_3 = 1$$

find the solution using the Gauss-Seidel method. Use

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

as the initial guess.

Solution

Rewriting the equations, we get

$$x_1 = \frac{76 - 7x_2 - 13x_3}{3}$$

$$x_2 = \frac{28 - x_1 - 3x_3}{5}$$

$$x_3 = \frac{1 - 12x_1 - 3x_2}{-5}$$

Assuming an initial guess of

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

the next six iterative values are given in the table below.

Iteration	x_1	$ \epsilon_{a_1} \%$	x_2	$ \epsilon_{a_2} \%$	x_3	$ \epsilon_{a_3} \%$
1	21.000	95.238	0.80000	100.00	50.680	98.027
2	-196.15	110.71	14.421	94.453	-462.30	110.96
3	1995.0	109.83	-116.02	112.43	4718.1	109.80
4	-20149	109.90	1204.6	109.63	-47636	109.90
5	2.0364×10^5	109.89	-12140	109.92	4.8144×10^5	109.89
6	-2.0579×10^6	109.89	1.2272×10^5	109.89	-4.8653×10^6	109.89

You can see that this solution is not converging and the coefficient matrix is not diagonally dominant. The coefficient matrix

$$[A] = \begin{bmatrix} 3 & 7 & 13 \\ 1 & 5 & 3 \\ 12 & 3 & -5 \end{bmatrix}$$

is not diagonally dominant as

$$|a_{11}| = |3| = 3 \leq |a_{12}| + |a_{13}| = |7| + |13| = 20$$

Hence, the Gauss-Seidel method may or may not converge.

However, it is the same set of equations as the previous example and that converged. The only difference is that we exchanged first and the third equation with each other and that made the coefficient matrix not diagonally dominant.

Therefore, it is possible that a system of equations can be made diagonally dominant if one exchanges the equations with each other. However, it is not possible for all cases. For example, the following set of equations

$$x_1 + x_2 + x_3 = 3$$

$$2x_1 + 3x_2 + 4x_3 = 9$$

$$x_1 + 7x_2 + x_3 = 9$$

cannot be rewritten to make the coefficient matrix diagonally dominant.

SIMULTANEOUS LINEAR EQUATIONS

Topic	Gauss-Seidel Method – More Examples
Summary	Textbook notes of the Gauss-Seidel method
Major	Electrical Engineering
Authors	Atar Kaw
Date	August 8, 2009
Web Site	http://numericalmethods.eng.usf.edu
