Parallelized matrix-vector multiplication of an upper triangular matrix with only odd indexed rows filled, generated in CSR form

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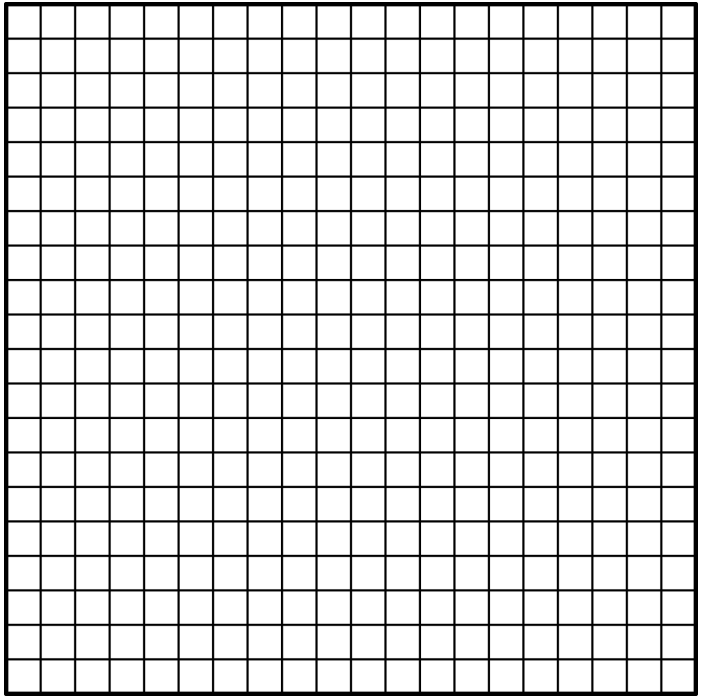
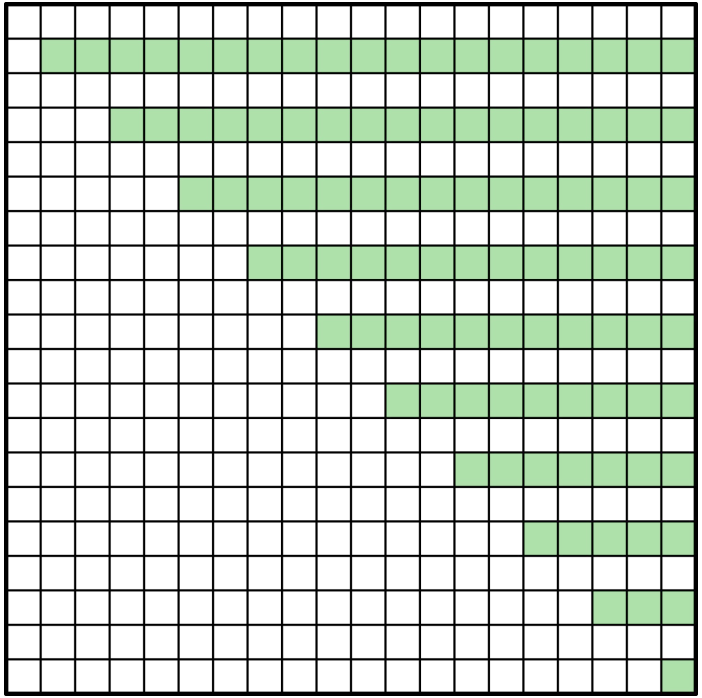
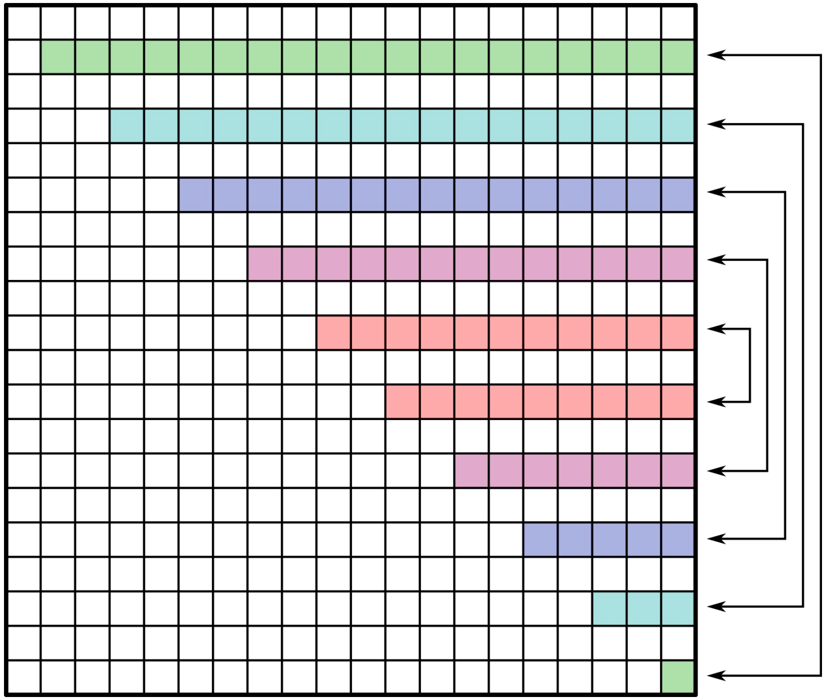
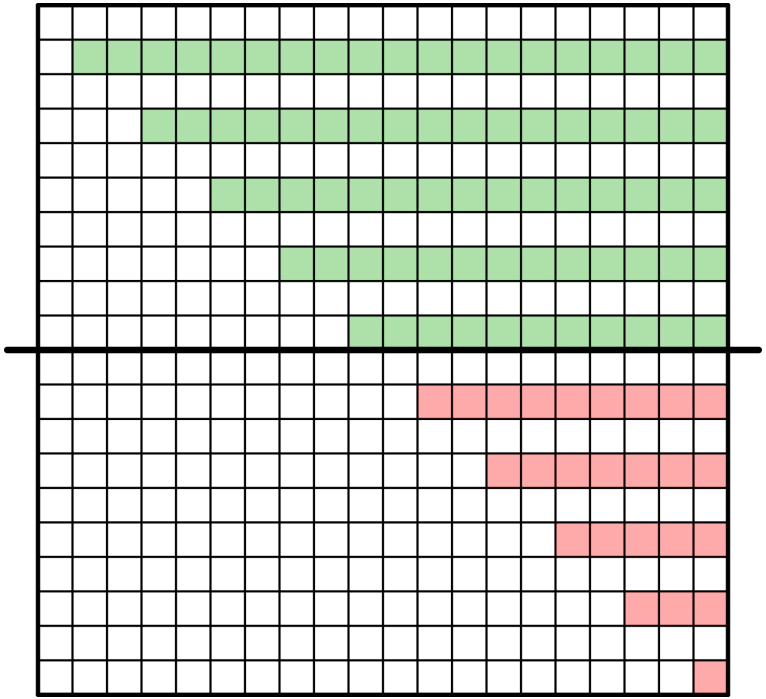
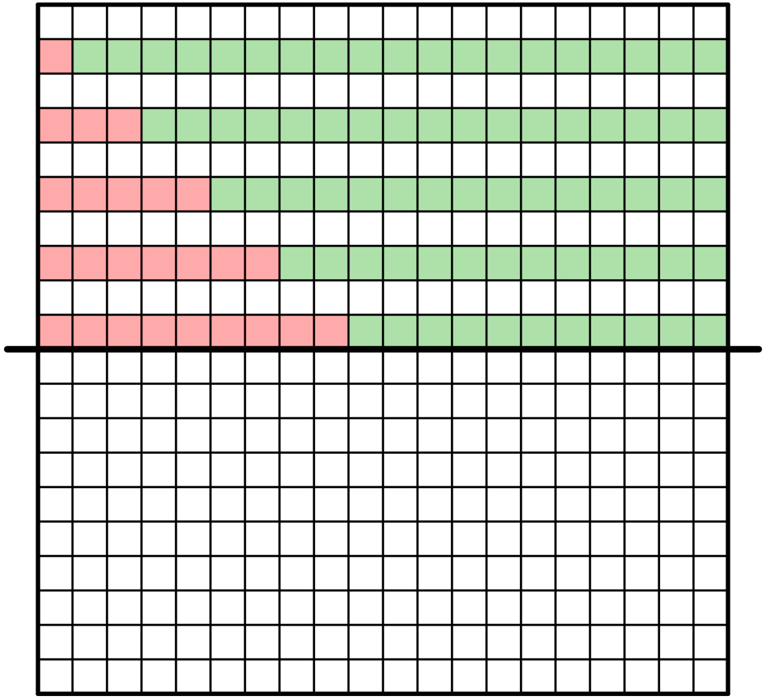
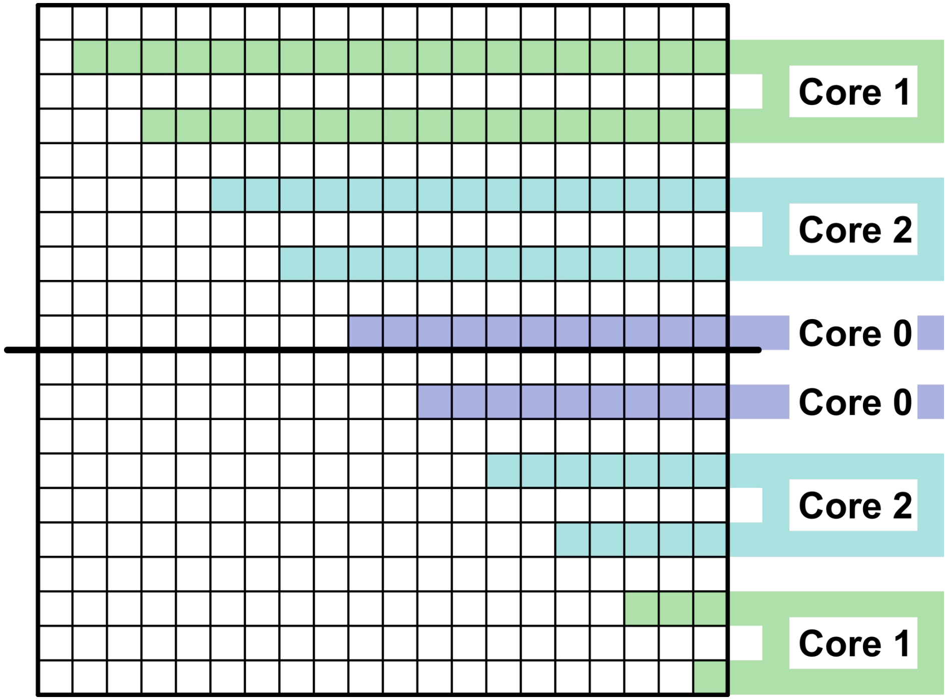












Core 1
Core 2
Core 0
Core 0
Core 2
Core 1

Taking matrix size and calculating the row numbers

```
int mat_n[argc-1];
for(i=1;i<argc;i++)
    mat_n[i-1] = atoi(argv[i]);

for(m=0;m<argc-1;m++){

    mat_size = mat_n[m];
    nnz_count = mat_size * mat_size / 4;

    // Calculate how many rows each core will get
    worker_rows = (mat_size / 4) / (core_count - 1);
    master_rows = (mat_size / 4) - worker_rows * (core_count - 1);
    // A unique variable for each core that takes different values if master or worker
    core_rows = (rank != 0) ? worker_rows : master_rows;
```

Preparing the arrays in master core

```
if (rank == 0){
    // Fill the vector to be multiplied in master core
    fillVecRand(vec, mat_size);

    // Allocate memory and fill values array
    memoryAllocationDouble(&values, nnz_count);
    fillVecRand(values, nnz_count);

    // Allocate memory and fill row_start and col_idx arrays
    memoryAllocationInt(&row_start, mat_size+1);
    memoryAllocationInt(&col_idx, nnz_count);
    fillCSR(row_start, col_idx, nnz_count, mat_size);

    //matVecMult(values, row_start, col_idx, vec, res_vec, mat_size);
    //printArrays(res_vec, row_start, col_idx, nnz_count, mat_size);
}
// Broadcast vec to every core
MPI_Bcast(vec, mat_size, MPI_DOUBLE, 0, MPI_COMM_WORLD);
```

Master core sending non-zero elements with their col_idx

```
elements_to_be_sent=0; total_sent=0; remaining_to_be_received=0;
for(i=1;i<core_count;i++){

    elements_to_be_sent = mat_size * worker_rows - worker_rows * worker_rows * ( 2*i-1);
    remaining_to_be_received += mat_size * worker_rows - elements_to_be_sent;
    MPI_Send(&elements_to_be_sent, 1, MPI_INT, i, 0, MPI_COMM_WORLD);

    MPI_Send(&values[total_sent], elements_to_be_sent, MPI_DOUBLE, i,  1, MPI_COMM_WORLD);
    MPI_Send(&values[nnz_count-remaining_to_be_received], mat_size * worker_rows - elements_to_be_sent,
            MPI_DOUBLE, i,  2, MPI_COMM_WORLD);

    MPI_Send(&col_idx[total_sent], elements_to_be_sent, MPI_INT, i,  3, MPI_COMM_WORLD);
    MPI_Send(&col_idx[nnz_count-remaining_to_be_received], mat_size * worker_rows - elements_to_be_sent,
            MPI_INT, i,  4, MPI_COMM_WORLD);

    total_sent += elements_to_be_sent;
}
```

Point-to-Point Communication

Worker cores receiving and performing the multiplication

```
}else{
    // Worker cores receive their respective parts of arrays values and col_idx
    MPI_Recv(&elements_to_be_sent, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status);

    memoryAllocationDouble(&values_cores, core_rows*mat_size);
    MPI_Recv(&values_cores[0], elements_to_be_sent, MPI_DOUBLE, 0, 1, MPI_COMM_WORLD, &status);
    MPI_Recv(&values_cores[elements_to_be_sent], worker_rows * mat_size - elements_to_be_sent, MPI_DOUBLE, 0, 2, MPI_COMM_WORLD, &status);

    memoryAllocationInt(&col_idx_cores, core_rows*mat_size);
    MPI_Recv(&col_idx_cores[0], elements_to_be_sent, MPI_INT, 0, 3, MPI_COMM_WORLD, &status);
    MPI_Recv(&col_idx_cores[elements_to_be_sent], worker_rows * mat_size - elements_to_be_sent, MPI_INT, 0, 4, MPI_COMM_WORLD, &status);

    // res_vec_cores is calculated
    matVecMult_Calc(values_cores, col_idx_cores, vec, res_vec_cores, mat_size, worker_rows, rank, elements_to_be_sent);

    // Calculated results get sent to master core
    MPI_Send(&res_vec_cores[0], core_rows, MPI_DOUBLE, 0, 5, MPI_COMM_WORLD);
    MPI_Send(&res_vec_cores[core_rows], worker_rows, MPI_DOUBLE, 0, 6, MPI_COMM_WORLD);
}
```

Point-to-Point Communication

Master core receiving and arranging the result vector

```
// Master calculates its own part if any rows are left after the split
elements_to_be_sent = (3*nnz_count/4-total_sent);
if(master_rows != 0){
    matVecMult_Calc(&values[total_sent], &col_idx[total_sent], vec,
                    &res_vec[mat_size/4-master_rows], mat_size, master_rows,
                    rank, elements_to_be_sent);

}

// Master collects res_vec_cores arrays from cores and fills res_vec
for(i=1;i<core_count;i++){
    MPI_Recv(&res_vec[worker_rows*(i-1)], worker_rows, MPI_DOUBLE, i, 5, MPI_COMM_WORLD, &status);
    MPI_Recv(&res_vec[mat_size/2-worker_rows*i], worker_rows, MPI_DOUBLE, i, 6,
             MPI_COMM_WORLD, &status);
}
```

Point-to-Point Communication

Master core sending each core their respective parts

```
// Master core scatters the values and col_idx arrays using the arrays
// sent_cnt1, send_cnt2, send_disp1, send_disp2
MPI_Scatterv(values, send_cnt1, send_disp1, MPI_DOUBLE,
             values_cores, send_cnt1[rank], MPI_DOUBLE, 0, MPI_COMM_WORLD);
MPI_Scatterv(values, send_cnt2, send_disp2, MPI_DOUBLE,
             &values_cores[send_cnt1[rank]], send_cnt2[rank], MPI_DOUBLE, 0, MPI_COMM_WORLD);

MPI_Scatterv(col_idx, send_cnt1, send_disp1, MPI_INT,
             col_idx_cores, send_cnt1[rank], MPI_INT, 0, MPI_COMM_WORLD);
MPI_Scatterv(col_idx, send_cnt2, send_disp2, MPI_INT,
             &col_idx_cores[send_cnt1[rank]], send_cnt2[rank], MPI_INT, 0, MPI_COMM_WORLD);

// Master calculates its own part if any rows are left after the scatter step
if (core_rows != 0){
    matVecMult_Calc(values_cores, col_idx_cores, vec, res_vec_cores, mat_size, core_rows, rank,
                    elements_to_be_sent);
}
```

Collective Communication

Master core gathering the calculated results into res_vec

```
// Master core gathers the values_cores and col_idx_cores arrays using the arrays
// sent_cnt1, send_disp1, send_disp2
MPI_Gatherv(res_vec_cores, core_rows, MPI_DOUBLE,
            res_vec, send_cnt1, send_disp1, MPI_DOUBLE, 0, MPI_COMM_WORLD);
MPI_Gatherv(res_vec_cores, core_rows, MPI_DOUBLE,
            res_vec, send_cnt1, send_disp2, MPI_DOUBLE, 0, MPI_COMM_WORLD);
```

Collective Communication

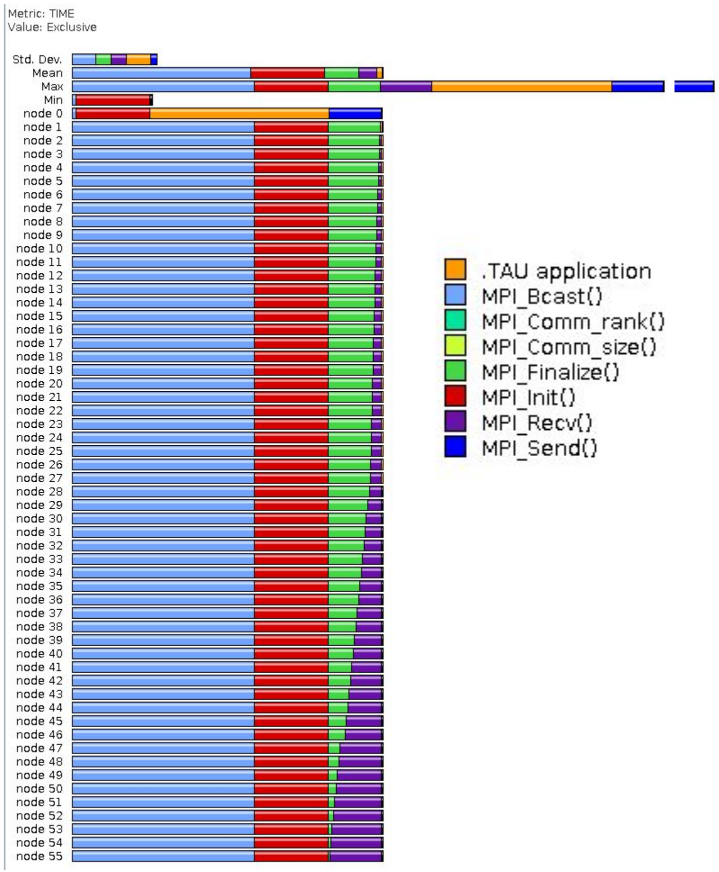
SPMV multiplication modified to work with my algorithm

```
void matVecMult_Calc(double *values, int *col_idx, double *vec, double *res_vec,
                     int mat_size, int row_number, int rank, int upper_half_elements){

    int i, j, comp=0;
    double sum;

    for(i=1 ; i<=row_number ; i++){
        sum = 0;
        for(j=0 ; j<for_limit(mat_size, rank, row_number, i, 1) ; j++)
            sum += values[comp+j] * vec[col_idx[comp+j]];
        res_vec[i-1] = sum;
        comp += j;
    }

    for(i=1 ; i<=row_number ; i++){
        sum = 0;
        for(j=0 ; j<for_limit(mat_size, rank, row_number, i, 0) ; j++){
            sum += values[comp+j] * vec[col_idx[comp+j]];
        }
        res_vec[i-1+row_number] = sum;
        comp += j;
    }
}
```



Metric: TIME
Value: Exclusive
Std. Dev.
Mean
Max
Min
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node 10
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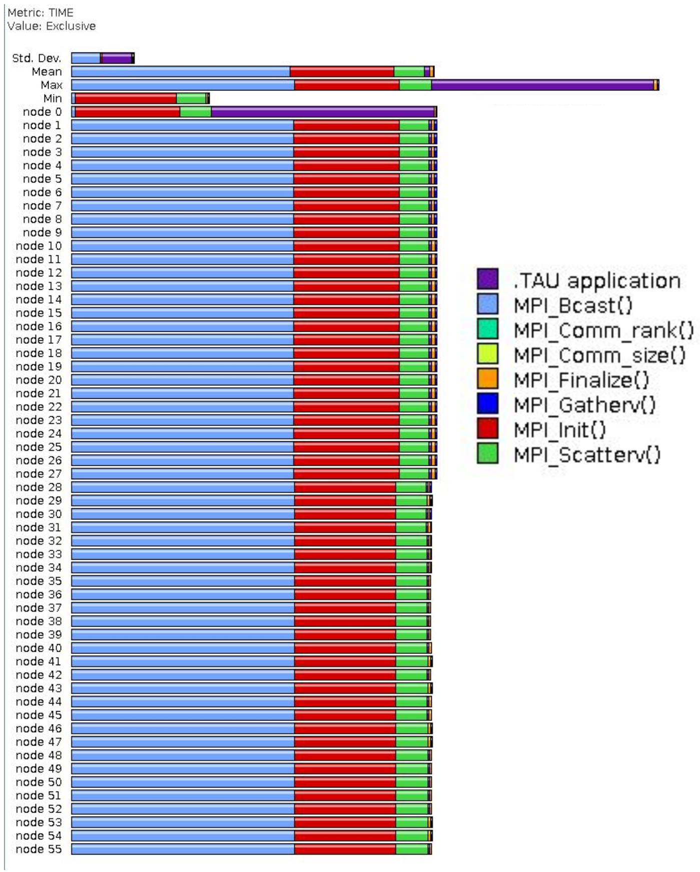
.TAU application
MPI_Bcast()
MPI_Comm_rank()
MPI_Comm_size()
MPI_Finalize()
MPI_Init()
MPI_Recv()
MPI_Send()



Metric: TIME
Value: Exclusive
Std. Dev.
Mean
Max
Min
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node 42
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node 55
.TAU application
MPI_Bcast()
MPI_Comm_rank()
MPI_Comm_size()
MPI_Finalize()
MPI_Gatherv()
MPI_Init()
MPI_Scatterv()

Matrix sizes