Uvod

Avtorji

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Problem

Problem n teles je klasičen problem v fiziki, kemiji in drugih področjih, saj z njim lahko opišemo mnogo interakcij v naravi (npr. med molekulami, nebesnimi telesi, ...). Danih imamo n teles, za vsakega pa podano še maso, začetni položaj in začetno hitrost. Telesa eno na drugo delujejo s gravitacijsko silo, torej se privlačijo. Zanima nas, kako se bo položaj in hitrost teles spreminjal skozi čas.

Za določitev premika in spremembe hitrosti telesa je potrebno izračunati razdaljo in smer do vsakega drugega telesa v sistemu. Kompleksnost problema z večanjem števila teles hitro narašča: za vsako telo je treba izračunati n^2 sil. Problem je zato visoko paralelen, z ustrezno paralelizacijo pa bi lahko problem pohitrili za pomemben faktor.

Sekvenčni algoritem

Najprej izpeljimo sekvenčni algoritem, ki bo služil kot osnova za vse paralelizacije.

Najprej ugotovimo, da bomo morali v vsaki različici programa vse iteracije (ena iteracija pomeni premik v eni časovni enoti) izvajati eno za drugo. Za izračun spremembe stanja vsakega telesa moramo namreč poznati vsa stanja teles v prejšnji iteraciji.

Metoda main

```
int main(int argc, char *argv[]) {
    // inicializacija
    Body **bodies;
    FILE *fp;
    int N_BODIES, N_ITER;

    if(argc != 3) {
        printf("Usage: %s <num_bodies> <num_iterations>\n", argv[0]);
        exit(1);
    }

    N_BODIES = atoi(argv[1]);
    N_ITER = atoi(argv[2]);

    fp = fopen(LOG_FILE, "wa");

    if (fp == NULL)
        throw_err(__LINE__, errno);

    // naključno genereriramo začetna stanja teles
    bodies = generate_initial_population(N_BODIES, 30, 3, 3);

    gettimeofday(&tv1, NULL);

    // izvedemo zeljeno stevilo iteracij
    for(int i = 0; i < N_ITER; i ++) {

        // vsako 100. iteracijo zapisemo v datoteko
        if (i % 100 == 0) {
            print_boddies(bodies, N_BODIES, i, fp);
        }

        // izracunamo stanja v naslednji iteraciji
        bodies = calculate_iteration(bodies, N_BODIES);
    }

    gettimeofday(&tv2, NULL);

    printf ("CPU: %f seconds\n", (float) (tv2.tv_usec - tv1.tv_usec) / 1000000 +
         (float) (tv2.tv_sec - tv1.tv_sec));

    print_boddies(bodies,N_BODIES, N_ITER, fp);

    cleanup(bodies, N_BODIES);
    fclose(fp);
```

```
    return 0;
}
```

Izračun naslednje iteracije

Izračun naslednje iteracije delamo v *for* zanki za vsako telo (indeks i). Znotraj izračuna spremembe stanja za vsako telo delo razdelimo v še eno zanko - ta računa sile, s katerimi vsako drugo telo deluje na trenutno telo.

```
Body **calculate_iteration(Body** bodies, int num_bodies) {
    Body** new_bodies = (Body**) malloc(num_bodies * sizeof(Body*));
    if(new_bodies == NULL)
        throw_err(__LINE__, 1);
    for (int i = 0; i < num_bodies; i++) {
        new_bodies[i] = malloc(sizeof(Body));
        if(new_bodies[i] == NULL)
            throw_err(__LINE__, 1);
        float forceX = 0;
        float forceY = 0;
        float forceZ = 0;
        for (int j = 0; j < num_bodies; j++) {
            float rx = bodies[j]->x - bodies[i]->x;
            float ry = bodies[j]->y - bodies[i]->y;
            float rz = bodies[j]->z - bodies[i]->z;
            float distance = sqrt(pow(rx, 2) + pow(ry, 2) + pow(rz, 2));

            forceX += bodies[j]->mass * rx / (pow(distance, 3) + EPSILON);
            forceY += bodies[j]->mass * ry / (pow(distance, 3) + EPSILON);
            forceZ += bodies[j]->mass * rz / (pow(distance, 3) + EPSILON);
        }

        forceX *= G * bodies[i]->mass;
        forceY *= G * bodies[i]->mass;
        forceZ *= G * bodies[i]->mass;

        float ax = forceX / bodies[i]->mass;
        float ay = forceY / bodies[i]->mass;
        float az = forceZ / bodies[i]->mass;

        new_bodies[i]->mass = bodies[i]->mass;
        new_bodies[i]->vx = bodies[i]->vx + ax * DT;
        new_bodies[i]->vy = bodies[i]->vy + ay * DT;
        new_bodies[i]->vz = bodies[i]->vz + az * DT;
        new_bodies[i]->x = bodies[i]->x + bodies[i]->vx * DT + 0.5 * ax * pow(DT, 2);
        new_bodies[i]->y = bodies[i]->y + bodies[i]->vy * DT + 0.5 * ay * pow(DT, 2);
        new_bodies[i]->z = bodies[i]->z + bodies[i]->vz * DT + 0.5 * az * pow(DT, 2);

    }

    cleanup(bodies, num_bodies);
    return new_bodies;
}
```

Sekvenčni algoritem - drugič

Ker za sile med telesi velja Fij = -Fji, lahko naredimo pol manj izračunov, vendar za to potrebujemo skoraj n-krat več prostora.

Program poteka podobno, le da moramo na začetku alocirati še matriko, ki bo držala vse sile med telesi:

```
bodies = generate_initial_population(N_BODIES, 30, 3, 3);

Force ***forces = malloc(sizeof(Force **) * N_BODIES);
for(int i = 0; i < N_BODIES; i++) {
    forces[i] = malloc(sizeof(Force *) * N_BODIES);
    for(int j = 0; j < i; j++) {
        forces[i][j] = malloc(sizeof(Force));
    }
}

for(int i = 0; i < N_ITER; i ++) {
    if (i % 100 == 0) {
        print_boddies(bodies, N_BODIES, i, fp);
    }
    bodies = calculate_iteration(bodies, forces, N_BODIES);
}
```

Izračun iteracije se sedaj spremeni tako, da najprej izračunamo vse sile med vsemi telesi in jih šele nato seštevamo:

```
Body **calculate_iteration(Body** bodies, Force ***forces,  int num_bodies) {
    Body **new_bodies = malloc(sizeof(Body *) * num_bodies);
    for (int i = 0; i < num_bodies; i++) {
        for (int j =0; j < i;  j++) {
            float rx = bodies[j]->x - bodies[i]->x;
            float ry = bodies[j]->y - bodies[i]->y;
            float rz = bodies[j]->z - bodies[i]->z;
            float distance = sqrt(pow(rx, 2) + pow(ry, 2) + pow(rz, 2));
            forces[i][j]-> fx = bodies[j]->mass * rx / (pow(distance, 3) + EPSILON);
            forces[i][j]-> fy = bodies[j]->mass * ry / (pow(distance, 3) + EPSILON);
            forces[i][j]-> fz = bodies[j]->mass * rz / (pow(distance, 3) + EPSILON);
        }
    }
    for(int i = 0; i < num_bodies; i++) {
        float forceX = 0;
        float forceY = 0;
        float forceZ = 0;

        for(int j = 0; j < i; j++) {
            forceX += forces[i][j]->fx;
            forceY += forces[i][j]->fy;
            forceZ += forces[i][j]->fz;
        }

        for(int j = i+1; j < num_bodies; j++) {
            forceX -= forces[j][i]->fx;
            forceY -= forces[j][i]->fy;
```

```
            forceZ -= forces[j][i]->fz;
        }

        forceX *= G * bodies[i]->mass;
        forceY *= G * bodies[i]->mass;
        forceZ *= G * bodies[i]->mass;


        float ax = forceX / bodies[i]->mass;
        float ay = forceY / bodies[i]->mass;
        float az = forceZ / bodies[i]->mass;

        new_bodies[i] = malloc(sizeof(Body));
        new_bodies[i]->mass = bodies[i]->mass;

        new_bodies[i]->vx = bodies[i]->vx + ax * DT;
        new_bodies[i]->vy = bodies[i]->vy + ay * DT;
        new_bodies[i]->vz = bodies[i]->vz + az * DT;

        new_bodies[i]->x = bodies[i]->x + bodies[i]->vx * DT + 0.5 * ax * pow(DT, 2);
        new_bodies[i]->y = bodies[i]->y + bodies[i]->vy * DT + 0.5 * ay * pow(DT, 2);
        new_bodies[i]->z = bodies[i]->z + bodies[i]->vz * DT + 0.5 * az * pow(DT, 2);

    }
    cleanup(bodies, num_bodies);
    return new_bodies;
}
```

Primerjava obeh sekvenčnih programov

n_bodies	n_steps	time1	time2
100	100	0.0134	0.0083
100	1000	0.1262	0.0824
100	10000	1.2691	0.827
1000	100	1.2722	2.3533
1000	1000	12.6684	23.8356
1000	10000	127.11	234.58
10000	100	126.47	

Ko je število teles majhno, je drugi program boljši, ko se število teles veča, pa število dostopov do pomnilnika in čas, ki ga s tem izgubimo, preseže čas, ki ga prihranimo z manj računanja. Za velike probleme je torej boljša prva verzija algoritma, ki ne izkoristi dejstva Fij = -Fji.

Paralelizacija z večnitenjem - Pthreads

Prvi način

V funkciji *main* naredimo *for* zanko, ki gre čez iteracije. Znotraj zanke vsakič ustvarimo niti, vsaka nit izračuna svoj del, potem pa niti pridružimo in nadaljujemo z naslednjo iteracijo.

Funkcija *main*:

```
    // create starting population
    bodies = generate_initial_population(N_BODIES, 30, 3, 3);

    // initialize thread args
    for(int i = 0; i < N_THREADS; i++) {
        thread_args[i].tid = i;
        thread_args[i].bodies = bodies;
        thread_args[i].n_bodies = N_BODIES;
        thread_args[i].start = i * N_BODIES / N_THREADS;
        thread_args[i].end = (i + 1) * N_BODIES / N_THREADS;
    }

    for(int i = 0; i < N_ITER; i ++) {

        if(i % 100 == 0) {
            print_boddies(bodies, N_BODIES, i, fp);
        }

        // Compute iteration
        for(int j = 0; j < N_THREADS; j++)
            if(pthread_create(&threads[j], NULL, parallel_iteration, (void *)
&thread_args[j]) != 0)
                throw_err(__LINE__, errno);

        // Join threads
        for(int j = 0; j < N_THREADS; j++){
            void *thread_result;
            if(pthread_join(threads[j], &thread_result) != 0)
                throw_err(__LINE__, errno);
            else {
               ThreadArgs *args = (ThreadArgs *) thread_result;
               memcpy(&thread_args[args->tid], args, sizeof(ThreadArgs));
            }
        }
        cleanup(bodies, N_BODIES); // fix the memory leak

        // Join bodies arrays
        for(int j = 0; j < N_THREADS; j++)
            for(int k = thread_args[j].start; k < thread_args[j].end; k++)
                bodies[k] = thread_args[j].bodies[k - thread_args[j].start];


        // Update bodies array for every thread
        for(int j = 0; j < N_THREADS; j++) {
            free(thread_args[j].bodies);
            thread_args[j].bodies = bodies;
```

```
        }

    }
```

Funkcija *parallel_iteration*, ki jo izvaja ena nit:

```
void *parallel_iteration(void *arg) {
    ThreadArgs *args = (ThreadArgs *) arg;
    Body **new_bodies = calculate_iteration(args->bodies, args->n_bodies, args->start,
args->end);
    args->bodies = new_bodies;
    pthread_exit((void*) args);
}
```

calculate_iteration je ista kot v sekvenčnem programu, le da zdaj računa spremembe stanj teles z indeksi na intervalu [*args->start*, *args->end*].

Drugi način

Prvi način nitenja s Pthreads je morda neučinkovit, ker v vsaki iteraciji ustvarjamo in uničujemo niti. To smo poskusili odpraviti:

```
Body *calculate_iteration(Body* bodies, int num_bodies, int start, int end) {
    int n_bodies_to_process = end - start;
    Body* new_bodies = (Body*) malloc((n_bodies_to_process) * sizeof(Body));

    ...

    return new_bodies;
}

void *parallel_iteration(void *arg) {
    ThreadData *thread_descriptor = (ThreadData *) arg;
    ThreadData master_descriptor = thread_data_g[0];

    fflush(stdout);

    for(int i = 0; i < thread_descriptor->n_iter; i++) {
        thread_descriptor->new_bodies = calculate_iteration(thread_descriptor->bodies,
thread_descriptor->n_bodies, thread_descriptor->start, thread_descriptor->end);

        // copy all bodies from new_bodies to bodies of the master thread
        memcpy(&master_descriptor.bodies[thread_descriptor->start], thread_descriptor-
>new_bodies, (thread_descriptor->end - thread_descriptor->start) * sizeof(Body));

        free(thread_descriptor->new_bodies);

        thread_descriptor->bodies = master_descriptor.bodies;

        pthread_barrier_wait(&barrier);

        if(thread_descriptor->tid == 0 && i % 100 == 0) {
            print_boddies(master_descriptor.bodies, master_descriptor.n_bodies, i, fp);
        }
```

```
    }


    return NULL;
}

int main(int argc, char *argv[]) {

    ...

    bodies = generate_initial_population(N_BODIES, 30, 3, 3);

    // initialize thread data
    for(int i = 0; i < N_THREADS; i++) {
        thread_data_g[i].tid = i;
        thread_data_g[i].bodies = bodies;
        thread_data_g[i].n_bodies = N_BODIES;
        thread_data_g[i].start = i * N_BODIES / N_THREADS;
        thread_data_g[i].end = (i + 1) * N_BODIES / N_THREADS;
        thread_data_g[i].n_iter = N_ITER;
        thread_data_g[i].n_threads = N_THREADS;
    }

    ...

    // Compute iteration
    for(int j = 0; j < N_THREADS; j++)
        if(pthread_create(&threads[j], NULL, parallel_iteration, (void *)
&thread_data_g[j]) != 0)
            throw_err(__LINE__, errno);

    // Join threads
    for(int j = 0; j < N_THREADS; j++)
        if(pthread_join(threads[j], NULL) != 0)
            throw_err(__LINE__, errno);

    ...

}
```

Tretji način

Tretji način je bil zelo podoben drugemu, le da smo odpravili še vsakokratno alociranje seznama lastnosti teles, tako da ves čas uporabljali iste spremenljivke.

```
void calculate_iteration(ThreadData *thread_descriptor) {

    ...

}

void *parallel_iteration(void *arg) {
    ThreadData *thread_descriptor = (ThreadData *) arg;
    ThreadData master_descriptor = thread_data_g[0];

    for(int i = 0; i < thread_descriptor->n_iter; i++) {
```

```
        calculate_iteration(thread_descriptor);

        pthread_barrier_wait(&barrier);

        // copy all bodies from new_bodies to bodies of the master thread
        memcpy(&master_descriptor.bodies[thread_descriptor->start], thread_descriptor-
>thread_bodies, (thread_descriptor->end - thread_descriptor->start) * sizeof(Body));

        thread_descriptor->bodies = master_descriptor.bodies;

        pthread_barrier_wait(&barrier);

        if(thread_descriptor->tid == 0 && i % 100 == 0) {
            print_boddies(master_descriptor.bodies, master_descriptor.n_bodies, i, fp);
        }
    }

    return NULL;
}

int main(int argc, char *argv[]) {

    ...

}
```

Rezultati

n_bodies	n_steps	n_threads	time0	time1	time2
100	100	1	0.014233	0.008753	0.012160
100	100	2	0.013511	0.005356	0.008089
100	100	4	0.014494	0.004058	0.006176
100	100	8	0.027422	0.005069	0.008342
100	100	16	0.057227	0.005910	0.009925
100	100	24	0.077586	0.007531	0.013549

n_bodies	n_steps	n_threads	time0	time1	time2
1000	100	1	0.846600	0.812971	1.226125
1000	100	2	0.537565	0.413167	0.625273
1000	100	4	0.288634	0.226370	0.414294
1000	100	8	0.213154	0.179878	0.265491
1000	100	16	0.158804	0.120838	0.152055
1000	100	24	0.162880	0.095325	0.126665

n_bodies	n_steps	n_threads	time0	time1	time2
10000	100	4	22.661427	22.408664	33.667507
10000	100	8	14.261958	11.592130	17.324320
10000	100	16	11.509391	11.351132	13.995063
10000	100	24	7.901652	7.776366	9.537391

n_bodies	n_steps	n_threads	time0	time1	time2
100000	100	8	1156.962800	1151.077168	1722.068115
100000	100	16	878.466339	874.805391	1208.428711
100000	100	24	770.176862	766.516877	953.110413

Opazimo, da je za veliko število teles drugi način rahlo boljši od prvega, tretji pa precej slabši.

Primerjava sekvenčnega programa s Pthreads

Primerjajmo čase za 10000 teles in 100 iteracij. Pri Pthreads gledamo drugo verzijo programa, ki se je izkazala najbolje.

```
ts = 126.47
```

p	čas	pohitritev	učinkovitost
4	22.41s	5.64	1.41
8	11.59s	10.91	1.36
16	11.35	11.14	0.70
24	7.78s	16.26	0.68

Paralelizacija z večnitenjem - OpenMP

```
Body **calculate_iteration(Body** bodies, int num_bodies) {
    Body** new_bodies = (Body**) malloc(num_bodies * sizeof(Body*));
    if(new_bodies == NULL)
        throw_err(__LINE__, 1);

    #pragma omp parallel for schedule(dynamic, 10)
    for (int i = 0; i < num_bodies; i++) {

        ...

    }

    cleanup(bodies, num_bodies);
    return new_bodies;
}


int main(int argc, char *argv[]) {
    Body **bodies;
    FILE *fp;
    int N_BODIES, N_ITER;

    if(argc != 3) {
        printf("Usage: %s <num_bodies> <num_iterations>\n", argv[0]);
        exit(1);
    }

    #pragma omp parallel
    #pragma omp master

    ...

    bodies = generate_initial_population(N_BODIES, 30, 3, 3);

    for(int i = 0; i < N_ITER; i ++) {
        if (i % 100 == 0) {
            print_boddies(bodies, N_BODIES, i, fp);
        }
        bodies = calculate_iteration(bodies, N_BODIES);
    }

    ...

}
```

Rezultati

Testirali smo tudi različne možnosti pri *#pragma parallel for*. Preizkusili smo vse kombinacije *static*, *dynamic* in *guided*, ter 1, 5, 10, 20, 50 na 8, 16 in 24 jedrih.

Strategije 0-4: static (1, 5, 10, 20, 50)
Strategije 5-9: dynamic (1, 5, 10, 20, 50)

Strategije 10-14: guided (1, 5, 10, 20, 50)

jeder	strategija	čas
8	0	21.089527
8	1	19.602837
8	2	19.432543
8	3	19.523254
8	4	19.284624
8	5	19.445204
8	6	19.593365
8	7	18.998045
8	8	19.307489
8	9	19.692074
8	10	19.157419
8	11	19.193727
8	12	19.154203
8	13	19.886925
8	14	19.939524

jeder	strategija	čas
16	0	24.277969
16	1	16.786196
16	2	16.139584
16	3	15.588262
16	4	15.464186
16	5	13.810653
16	6	13.262261
16	7	12.486407
16	8	12.594163
16	9	12.475571
16	10	14.055889
16	11	13.683089
16	12	13.832859
16	13	13.685722
16	14	14.045515

jeder	strategija	čas

jeder	strategija	čas
24	0	17.421495
24	1	14.145296
24	2	11.953074
24	3	10.958787
24	4	11.053214
24	5	16.372280
24	6	12.880569
24	7	11.966436
24	8	11.388126
24	9	11.551367
24	10	10.755853
24	11	10.992288
24	12	10.823830
24	13	10.913774
24	14	11.166388

V splošnem se je za zelo dobro izkazala strategija 7: *(dynamic, 10)*. Od tu naprej smo uporabljali to.

Časi pri različnih parametrih

n_bodies	n_steps	n_threads	time
100	100	1	0.024474
100	100	2	0.008635
100	100	4	0.006584
100	100	8	0.004472
100	100	16	0.004327
100	100	24	0.345345
100	1000	1	0.129204
100	1000	2	0.081089
100	1000	4	0.047296
100	1000	8	0.035851
100	1000	16	0.032883
100	1000	24	0.034667
1000	100	1	1.427507
1000	100	2	0.839148

n_bodies	n_steps	n_threads	time
1000	100	4	0.403707
1000	100	8	0.263962
1000	100	16	0.222550
1000	100	24	0.569689
1000	1000	1	12.776207
1000	1000	2	6.945390
1000	1000	4	3.908245
1000	1000	8	2.271151
1000	1000	16	1.754412
1000	1000	24	1.830235
10000	100	4	38.134682
10000	100	8	25.509295
10000	100	16	18.699974
10000	100	24	18.445520
10000	1000	4	385.852478
10000	1000	8	206.600891
10000	1000	16	151.315048
10000	1000	24	157.120377
100000	100	8	2121.112793
100000	100	16	1261.661865
100000	100	24	1220.236938
100000	100	16	1253.509155
100000	100	24	1224.000732

Primerjava sekvenčnega programa z OpenMP

Primerjajmo čase za 10000 teles in 100 iteracij.

```
ts = 126.47
```

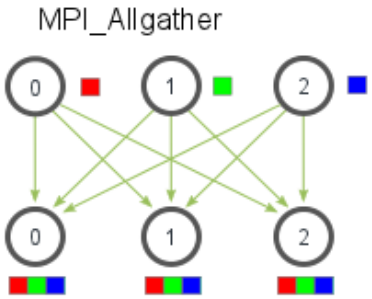
p	čas	pohitritev	učinkovitost
4	38.13s	3.32	0.83
8	25.51s	4.96	0.62
16	18.70s	6.76	0.42

p	čas	pohitritev	učinkovitost
24	18.45s	6.85	0.29

Paraleliziranje z MPI

Pri večnitenju na enem procesu nismo imeli težav, saj imajo vse niti dostop do istega skupnega pomnilnika. To je za program ključno, saj v i-ti iteraciji za izračun k-tega telesa potrebujemo podatke o popolnoma vseh telesih iz iteracije i-1.

Pri računanju na več procesih te prednosti nimamo. Procesi si bodo morali po vsaki iteraciji izmenjati podatke. Imamo situacijo, podobno spodnji:



Vsak proces ima torej del podatkov, ki jih mora razposlati vsem ostalim. To naredimo s pomočjo funkcije *MPI_Allgatherv()*.

```
Body *calculate_iteration(Body *bodies, int num_bodies, int start, int end)
{

    ...

    #pragma omp parallel for schedule(dynamic, 10)
    for (i = start; i < end; i++)
    {

        ...

    }

    return new_bodies;
}

int main(int argc, char *argv[])
{

    ...

    #pragma omp parallel
    #pragma omp master

    ...

    // MPI DATATYPE
    const int n_items=7;
    int blocklengths[7] = {1,1,1,1,1,1,1};
    MPI_Datatype types[7] = {MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT,
MPI_FLOAT, MPI_FLOAT};
    MPI_Datatype mpi_body_type;
    MPI_Aint offsets[7];
```

```
    offsets[0] = offsetof(Body, mass);
    offsets[1] = offsetof(Body, x);
    offsets[2] = offsetof(Body, y);
    offsets[3] = offsetof(Body, z);
    offsets[4] = offsetof(Body, vx);
    offsets[5] = offsetof(Body, vy);
    offsets[6] = offsetof(Body, vz);

    MPI_Type_create_struct(n_items, blocklengths, offsets, types, &mpi_body_type);
    MPI_Type_commit(&mpi_body_type);

    MPI_Bcast(bodies, N_BODIES, mpi_body_type, 0, MPI_COMM_WORLD);

    fflush(fp);
    gettimeofday(&tv1, NULL);
    for (int i = 0; i < N_ITER; i++)
    {
        Body *new_bodies = calculate_iteration(bodies, N_BODIES, displacement[myid],
displacement[myid] + count[myid]);

        MPI_Allgatherv(new_bodies, count[myid], mpi_body_type, bodies, count,
displacement, mpi_body_type, MPI_COMM_WORLD);
        free(new_bodies);
    }

    ...

    return 0;
}
```

MPI drugič

Zgornja implementacija z MPI ima eno očitno pomankljivost: prenašanje podatkov po vsaki iteraciji. Bolj optimalno bi bilo, če bi med prenašanjem podatkov procesi že računali naslednjo iteracijo. To lahko naredijo samo za telesa, za katere že imajo podatke - telesa, ki so jih računala sama v prejšnji iteraciji.

Uporabimo *MPI_Iallgatherv()* za asinhrono pošiljanje podatkov in *MPI_Wait()* za čakanje, ko izračunajo svoj del naslednje iteracije.

```
void compute_forces(Force *forces, Body *new_bodies, int start, int end){
    #pragma omp parallel for schedule(dynamic, 10)
    for(int i = start; i < end; i++) {

        ...

        for(int j = start; j <  end; j++) {

            ...

        }
    }
}

void compute_partial_iteration(Body *bodies, Force *forces, Body *new_bodies,  int
num_bodies, int start, int end){
    #pragma omp parallel for schedule(dynamic, 10)
```

```
    for(int i = start; i < end; i++) {
        for(int j = 0; j < num_bodies && (j < start || j > end); j++) {

            ...

        }

        ...

    }
}

Body *calculate_iteration(Body *bodies, int num_bodies, int start, int end)
{

    ...

    #pragma omp parallel for schedule(dynamic, 10)
    for (i = start; i < end; i++)
    {

        ...

    }

    return new_bodies;
}


int main(int argc, char *argv[])
{

    ...

    // MPI DATATYPE
    const int n_items=7;
    int blocklengths[7] = {1,1,1,1,1,1,1};
    MPI_Datatype types[7] = {MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT,
MPI_FLOAT, MPI_FLOAT};
    MPI_Datatype mpi_body_type;
    MPI_Aint offsets[7];

    offsets[0] = offsetof(Body, mass);
    offsets[1] = offsetof(Body, x);
    offsets[2] = offsetof(Body, y);
    offsets[3] = offsetof(Body, z);
    offsets[4] = offsetof(Body, vx);
    offsets[5] = offsetof(Body, vy);
    offsets[6] = offsetof(Body, vz);

    MPI_Type_create_struct(n_items, blocklengths, offsets, types, &mpi_body_type);
    MPI_Type_commit(&mpi_body_type);

    MPI_Bcast(bodies, N_BODIES, mpi_body_type, 0, MPI_COMM_WORLD);

    Body *new_bodies;
    Force *my_forces = calloc( count[myid],sizeof(Force) );

    for (int i = 0; i < N_ITER; i++)
```

```
    {
        if( i == 0)
            new_bodies = calculate_iteration(bodies, N_BODIES, displacement[myid],
displacement[myid] + count[myid]);
        else { // compute partial results out of new_bodies
            compute_forces(my_forces, new_bodies,  displacement[myid], displacement[myid]
+ count[myid]);
            // test if  allgather request is done
            MPI_Wait(&request, MPI_STATUS_IGNORE);
            // compute new bodies
            compute_partial_iteration(bodies, my_forces, new_bodies, N_BODIES,
displacement[myid], displacement[myid] + count[myid]);
        }

        MPI_Iallgatherv(new_bodies, count[myid], mpi_body_type, bodies, count,
displacement, mpi_body_type, MPI_COMM_WORLD, &request);
    }

    ...

    return 0;
}
```

Rezultati

```
ts = 123.58s
```

n_bodies	n_steps	n_procs	threads_per_proc	threads	version	time	pohitritev	učinkovitost
10000	100	1	1	1	0	123.579796	1.00	1.00
10000	100	1	2	2	0	61.942390	1.99	1.00
10000	100	1	4	4	0	33.588982	3.68	0.92
10000	100	1	8	8	0	17.143877	7.21	0.90
10000	100	1	16	16	0	10.707243	11.54	0.72
10000	100	2	1	2	0	61.855598	2.00	1.00
10000	100	2	2	4	0	33.641106	3.67	0.92
10000	100	2	4	8	0	17.154768	7.20	0.90
10000	100	2	8	16	0	11.247894	10.98	0.69
10000	100	4	1	4	0	33.683064	3.67	0.92
10000	100	4	2	8	0	17.230814	7.17	0.90
10000	100	4	4	16	0	11.951149	10.34	0.65
10000	100	8	1	8	0	17.298414	7.14	0.89
10000	100	8	2	16	0	13.116263	9.42	0.59
n_bodies	**n_steps**	**n_procs**	**threads_per_proc**	**threads**	**version**	**time**	**pohitritev**	**učinkovitost**
10000	100	1	1	1	1	138.753438	0.89	0.89
10000	100	1	2	2	1	70.221610	1.75	0.88
10000	100	1	4	4	1	38.308274	3.22	0.80
10000	100	1	8	8	1	19.503104	6.34	0.79
10000	100	1	16	16	1	12.620616	9.79	0.61
10000	100	2	1	2	1	65.807471	1.87	0.94
10000	100	2	2	4	1	37.023365	3.34	0.84
10000	100	2	4	8	1	18.721396	6.60	0.83
10000	100	2	8	16	1	10.374856	11.91	0.74
10000	100	4	1	4	1	35.303909	3.50	0.88
10000	100	4	2	8	1	18.586854	6.65	0.83
10000	100	4	4	16	1	10.419683	11.86	0.74
10000	100	8	1	8	1	17.612471	7.01	0.88

n_bodies	n_steps	n_procs	threads_per_proc	threads	version	time	pohitritev	učinkovitost
10000	100	8	2	16	1	9.756163	12.67	0.79

Prvi način MPI je boljši pri manj procesih in nitih, takoj, ko dosežemo skupno 16 niti, ki se izvajajo na vsaj 2 procesih, pa se bolje obnese drugi način.

Paralelno pisanje v datoteko

V zgornjih MPI implementacijah izgubljamo dragoceni čas na ničtem procesu, ki zapisuje v datoteko. Zato smo pripravili še posebno implementacijo, ki poskrbi, da vsak proces sam zapisuje v skupno datoteko.

```
int main(int argc, char *argv[])
{

    ...

    #pragma omp parallel
    #pragma omp master

    ...

    // MPI DATATYPE
    const int n_items = 7;
    int blocklengths[7] = {1, 1, 1, 1, 1, 1, 1};
    MPI_Datatype types[7] = {MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT, MPI_FLOAT,
MPI_FLOAT, MPI_FLOAT};
    MPI_Datatype mpi_body_type;
    MPI_Aint offsets[7];

    offsets[0] = offsetof(Body, mass);
    offsets[1] = offsetof(Body, x);
    offsets[2] = offsetof(Body, y);
    offsets[3] = offsetof(Body, z);
    offsets[4] = offsetof(Body, vx);
    offsets[5] = offsetof(Body, vy);
    offsets[6] = offsetof(Body, vz);

    MPI_Type_create_struct(n_items, blocklengths, offsets, types, &mpi_body_type);
    MPI_Type_commit(&mpi_body_type);
    int s;
    MPI_Type_size(mpi_body_type, &s);
    MPI_Bcast(bodies, N_BODIES, mpi_body_type, 0, MPI_COMM_WORLD);
    MPI_File_set_view(file, 0, mpi_body_type, mpi_body_type, "native", MPI_INFO_NULL);
    gettimeofday(&tv1, NULL);
    for (int i = 0; i < N_ITER; i++)
    {

        Body *new_bodies = calculate_iteration(bodies, N_BODIES, displacement[myid],
displacement[myid] + count[myid]);
        MPI_Allgatherv(new_bodies, count[myid], mpi_body_type, bodies, count,
displacement, mpi_body_type, MPI_COMM_WORLD);
        MPI_Offset offset = i * N_BODIES + displacement[myid];
        MPI_File_write_at(file, offset, new_bodies, count[myid], mpi_body_type,
MPI_STATUS_IGNORE);
        free(new_bodies);
    }
```

```
    ...
}
```

Primerjava paralelizacij

Primerjajmo najboljše parametre za vsako tehnologijo paralelizacije pri 10000 telesih in 100 iteracijah:

```
ts = 126.47
```

Tehnologija	Št. procesov	Št. niti na proces	Čas	Pohitritev	Učinkovitost
Pthreads	1	16	11.35	11.14	0.70
OpenMP	1	16	18.70	6.76	0.42
MPI	8	2	9.756	12.97	0.81