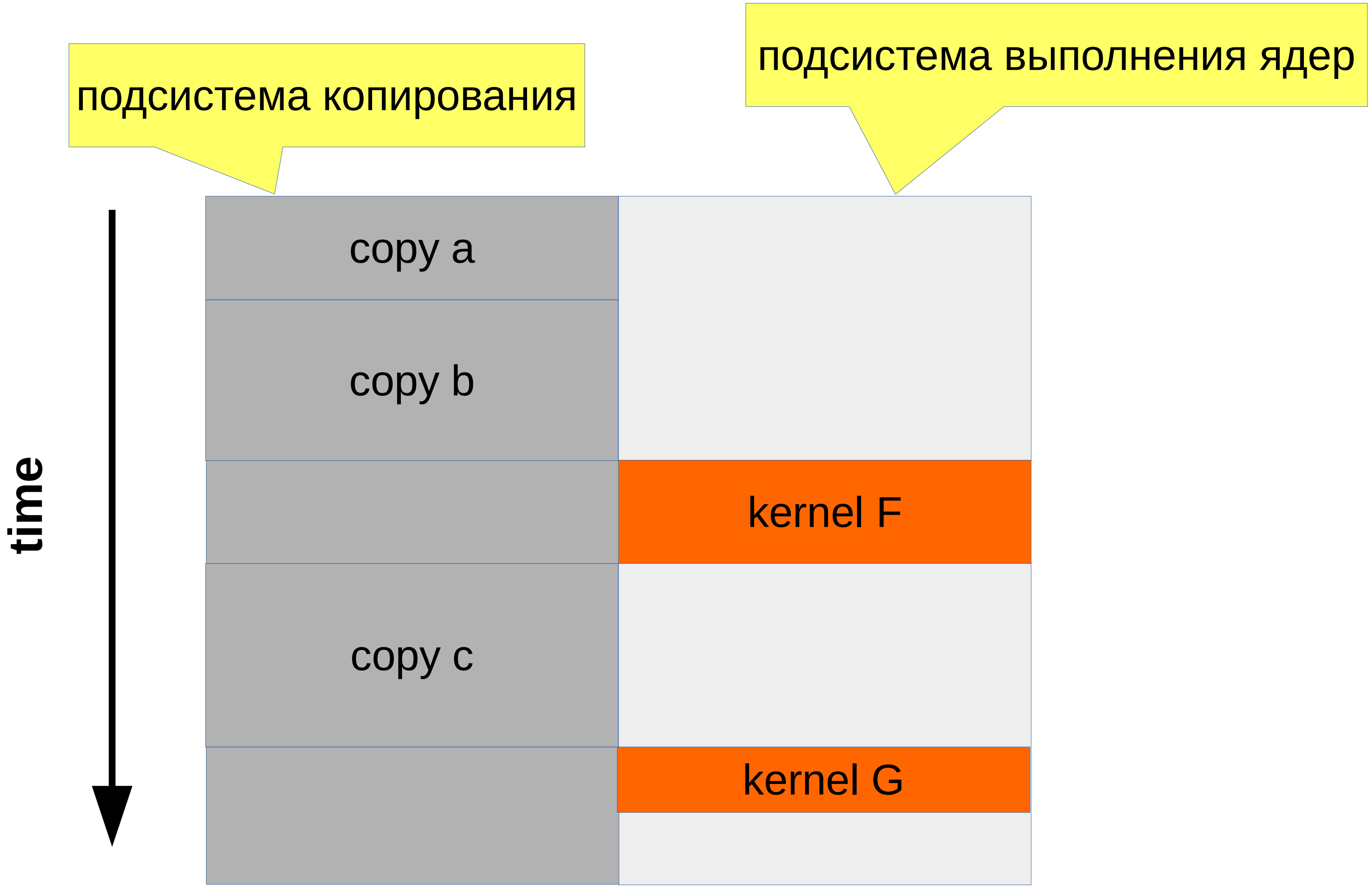
Лекция 5

Потоки CUDA (*CUDA Streams*)

- pinned-память - закрепленные страницы памяти;
- CUDA Streams – очереди команд;
- Мульти GPU

Возможность одновременного копирования

```
Device 0: "GeForce GTX 560 Ti"
CUDA Driver Version / Runtime Version          7.5 / 7.5
CUDA Capability Major/Minor version number:    2.1
..................................................................................................
Concurrent copy and kernel execution:          Yes with 1 copy engine(s)
..................................................................................................
```



подсистема копирования

подсистема выполнения ядер

Потоки CUDA и разрешение зависимостей при распараллеливании копирования и выполнения

(I)

Очередь копирования	*Очередь выполнения*
stream0, copy a	
stream0, copy b	
блокировка	kernel0
stream0, copy c	
stream1, copy a	
stream1, copy b	
блокировка	kernel1
stream1, copy c	

(II)

Очередь копирования	*Очередь выполнения*
stream0, copy a	
stream0, copy b	
stream1, copy a	kernel0
stream1, copy b	
stream0, copy c	kernel1
stream1, copy c	

```
#define N (1024*1024)
#define FULL_DATA_SIZE  (N*20)

__global__ void kernel(int* a, int* b, int* c){
  int idx=threadIdx.x+blockIdx.x*blockDim.x;
  if(idx<N){
    int idx1=(idx+1)%256;
    int idx2=(idx+2)%256;
    float as=(a[idx]+a[idx1]+a[idx2])/3.0f;
    float bs=(b[idx]+b[idx1]+b[idx2])/3.0f;
    c[idx]=(as+bs)/2;
  }
}
int main(){
  cudaDeviceProp prop;
  int whichDevice;

  cudaGetDevice(&whichDevice);
  cudaGetDeviceProperties(&prop, whichDevice);
  if(!prop.deviceOverlap){
    printf("Device does not support overlapping\n");
    return 0;
  }

  cudaEvent_t start, stop;
…..........................................................................................................
```

Sanders J., Kandrot E.
CUDA by Example, an introduction to general-purpose GPU programming,
Addison-Wesley, 2013.

Выделение закрепленной (*paged-locked*) памяти

```
cudaHostAlloc( (void**)&host_a, FULL_DATA_SIZE*sizeof(int),
             cudaHostAllocDefault);

cudaHostAlloc( (void**)&host_b, FULL_DATA_SIZE*sizeof(int),
  cudaHostAllocDefault);

cudaHostAlloc( (void**)&host_c, FULL_DATA_SIZE*sizeof(int),
cudaHostAllocDefault);
```

Константа ***cudaHostAllocDefault*** означает эквивалентность функций

```
__host__ cudaError_t cudaHostAlloc ( void** pHost, size_t size, unsigned int  flags )
```

и

```
__host__ cudaError_t cudaMallocHost ( void** ptr, size_t size )
```

```
…..............................................................................................................
cudaStream_t stream;
cudaStreamCreate(&stream );

 cudaEventRecord(start,0 );
 for(int i=0; i<FULL_DATA_SIZE; i+=N){

   cudaMemcpyAsync(dev_a, host_a+i, N*sizeof(int), cudaMemcpyHostToDevice, stream );
   cudaMemcpyAsync(dev_b, host_b+i, N*sizeof(int), cudaMemcpyHostToDevice, stream );

   kernel<<<N/256, 256, 0, stream>>>(dev_a, dev_b, dev_c);

   cudaMemcpyAsync(host_c+i, dev_c, N*sizeof(int), cudaMemcpyDeviceToHost, stream );
 }

 cudaStreamSynchronize( stream );

 cudaEventRecord(stop,0);
 cudaEventSynchronize(stop);
…....................................................................................................
```

(I)

```
……………………………………………………………………………………………………..
cudaEventRecord( start, 0 );
for(int i=0; i<FULL_DATA_SIZE; i+=N*2){
//////////////////           ПЕРВЫЙ   ПОТОК        ////////////////////
   cudaMemcpyAsync(dev_a0, host_a+i, N*sizeof(int), cudaMemcpyHostToDevice, stream0 );
   cudaMemcpyAsync(dev_b0, host_b+i, N*sizeof(int), cudaMemcpyHostToDevice, stream0 );

   kernel<<<N/256, 256, 0, stream0>>>(dev_a0, dev_b0, dev_c0);

   cudaMemcpyAsync(host_c+i, dev_c0, N*sizeof(int), cudaMemcpyDeviceToHost, stream0 );

//////////////////        ВТОРОЙ   ПОТОК         ////////////////////
   cudaMemcpyAsync(dev_a1, host_a+i+N, N*sizeof(int),cudaMemcpyHostToDevice, stream1);
   cudaMemcpyAsync(dev_b1, host_b+i+N, N*sizeof(int),cudaMemcpyHostToDevice, stream1);

   kernel<<<N/256, 256, 0, stream1>>>(dev_a1, dev_b1, dev_c1);

   cudaMemcpyAsync(host_c+i+N, dev_c1, N*sizeof(int),cudaMemcpyDeviceToHost, stream1);
}

cudaStreamSynchronize( stream0 );
cudaStreamSynchronize( stream1 );

cudaEventRecord(stop,0);
cudaEventSynchronize(stop);
……………………………………………………………………………………………….
```

(II)

```
…..............................................................................................................................
cudaEventRecord(start,0)
for(int i=0; i<FULL_DATA_SIZE; i+=N*2){
///////////////////    ПЕРЕМЕЖАЕМЫЕ    ПОТОКИ    ///////////////////
  cudaMemcpyAsync(dev_a0, host_a+i, N*sizeof(int),cudaMemcpyHostToDevice, stream0 );
  cudaMemcpyAsync(dev_a1, host_a+i+N, N*sizeof(int),cudaMemcpyHostToDevice, stream1);

   cudaMemcpyAsync(dev_b0, host_b+i, N*sizeof(int), cudaMemcpyHostToDevice, stream0 );
   cudaMemcpyAsync(dev_b1, host_b+i+N, N*sizeof(int), cudaMemcpyHostToDevice, stream1);

   kernel<<<N/256, 256, 0, stream0>>>(dev_a0, dev_b0, dev_c0);
   kernel<<<N/256, 256, 0, stream1>>>(dev_a1, dev_b1, dev_c1);

   cudaMemcpyAsync(host_c+i, dev_c0, N*sizeof(int),cudaMemcpyDeviceToHost, stream0 );
   cudaMemcpyAsync(host_c+i+N, dev_c1, N*sizeof(int), cudaMemcpyDeviceToHost, stream1);
  }

  cudaStreamSynchronize( stream0 );
  cudaStreamSynchronize( stream1 );

  cudaEventRecord(stop,0 );
  cudaEventSynchronize(stop);
 …......................................................................................................................
```

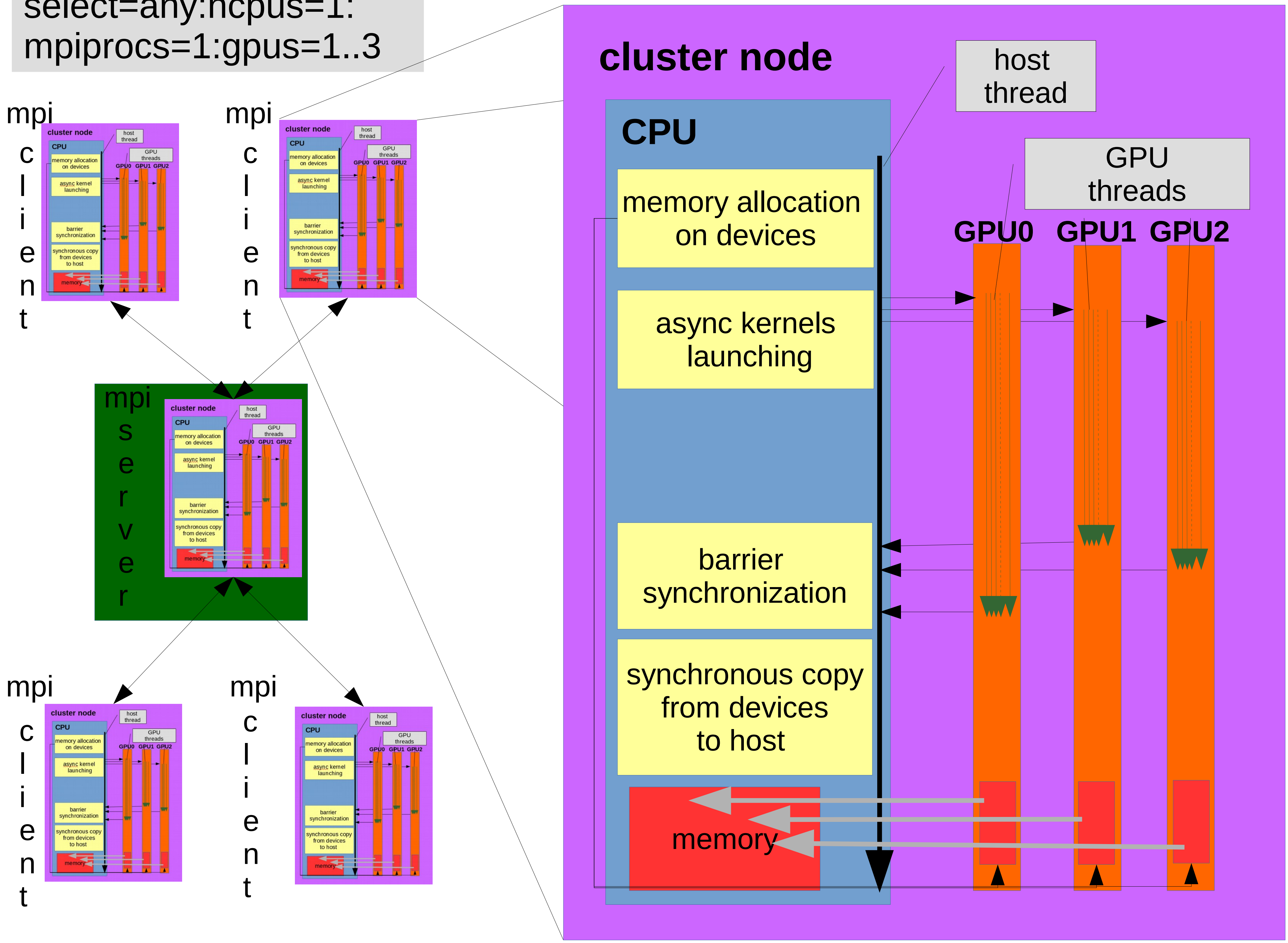
```
Device 0: "GeForce GTX 650"
  CUDA Driver Version / Runtime Version          6.5 / 6.5
  CUDA Capability Major/Minor version number:    3.0
  Total amount of global memory:                 2048 MBytes (2147155968 bytes)
  ( 2) Multiprocessors, (192) CUDA Cores/MP:     384 CUDA Cores
  GPU Clock rate:                                1110 MHz (1.11 GHz)
  Memory Clock rate:                             2500 Mhz
…...........................................................................................................
Concurrent copy and kernel execution:          Yes with 1 copy engine(s)
 Run time limit on kernels:                     Yes
 Integrated GPU sharing Host Memory:            No
…...........................................................................................................
```

```
malkov@dew:~/WORKSHOP/PROJECTS/CUDA-EXERCISE/CUDA_STREAMS> ./1
Elapsed time: 34.1 ms
malkov@dew:~/WORKSHOP/PROJECTS/CUDA-EXERCISE/CUDA_STREAMS> ./2
Elapsed time: 34.1 ms
malkov@dew:~/WORKSHOP/PROJECTS/CUDA-EXERCISE/CUDA_STREAMS> ./3
Elapsed time: 23.7 ms
malkov@dew:~/WORKSHOP/PROJECTS/CUDA-EXERCISE/CUDA_STREAMS>
```

```
Device 0: "GeForce GTX 560 Ti"
CUDA Driver Version / Runtime Version          7.5 / 7.5
CUDA Capability Major/Minor version number:    2.1
Total amount of global memory:                 2047 MBytes (2145927168 bytes)
( 8) Multiprocessors, ( 48) CUDA Cores/MP:     384 CUDA Cores
GPU Max Clock rate:                            1645 MHz (1.64 GHz)
Memory Clock rate:                             2004 Mhz
 …...........................................................................................................
Concurrent copy and kernel execution:          Yes with 1 copy engine(s)
Run time limit on kernels:                     Yes
Integrated GPU sharing Host Memory:            No
…..............................................................................................................
```

```
malkov@linux-5002:~/WORKSHOP/CUDA EXERCISE/CUDA STREAMS> ./1
Elapsed time: 44.1 ms
malkov@linux-5002:~/WORKSHOP/CUDA EXERCISE/CUDA STREAMS> ./2
Elapsed time: 44.4 ms
malkov@linux-5002:~/WORKSHOP/CUDA EXERCISE/CUDA STREAMS> ./3
Elapsed time: 41.6 ms
```

select=any:ncpus=1:
mpiprocs=1:gpus=1..3



Выделение памяти

Выделение памяти на хосте:

```
 float**  Df_device=(float**)calloc(NG, sizeof(REAL*));
 float**  St_device=(float**)calloc(NG, sizeof(REAL*));
```

Выделение памяти на устройствах:

```
  for(int idev=0;idev< NG; idev++){
    cudaSetDevice(assigned_devices[idev]);
       cudaMalloc((void **) &Df_device[idev], size_of_Df/NG);
       cudaMalloc((void **) &St_device[idev], size_of_Df/NG);
 }
```

NG – количество GPU.

idev – номер GPU.

assigned_devices[idev] – идентификатор GPU.

Df_device[idev], St_device[idev] – порции массивов, предназначенные для GPU с номером idev.

Асинхронный запуск ядер и барьерная синхронизация.

```
cudaEvent_t  *mdEventStart=(cudaEvent_t*)calloc(NG, sizeof(cudaEvent_t));
cudaEvent_t  *mdEventStop=(cudaEvent_t*)calloc(NG, sizeof(cudaEvent_t));
```

```
for(int idev=0;idev< NG; idev++){
      cudaSetDevice(assigned_devices[idev]);
             cudaEventCreate(&mdEventStart[idev]);
             cudaEventCreate(&mdEventStop[idev]);
}
```

```
for(int idev=0;idev< NG; idev++){
      cudaSetDevice(assigned_devices[idev]);
           cudaEventRecord( mdEventStart[idev], 0 );
           gStossCalc<<<dim3(nvx, nvy,nvz), dim3(SPACE_CELL_OFFSET)>>>
                                                (Df_device[idev], St_device[idev],  N/NG,  l_offset);
           cudaEventRecord( mdEventStop[idev], 0);
}
```

```
for(int idev=0;idev< NG; idev++){
      cudaSetDevice(assigned_devices[idev]);
             cudaEventSynchronize(mdEventStop[idev]);
}
```

Синхронное копирование с устройств на хост

```
for(int idev=0;idev< NG; idev++){
  cudaSetDevice(assigned_devices[idev]);
   cudaMemcpy(St+idev*size_of_DF/NG, St_device[idev],
          size_of_Df/NG, cudaMemcpyDeviceToHost);
}
```

(1 GPU)

```
NG=1    gCalculateParams      Elapsed time: 1.55024
gClearStoss         gClearStoss        Elapsed time: 0.213664
gTransposeDf        Elapsed time: 5.2569
gStossCalc    Elapsed time: 246532
gTransposeDfInverse   Elapsed time: 7.51043
gClearStoss         gClearStoss        Elapsed time: 0.217504
gTransposeDf        Elapsed time: 5.25312
gStossCalc    Elapsed time: 246536
gTransposeDfInverse   Elapsed time: 7.53414
gClearStoss         gClearStoss        Elapsed time: 0.217088
gTransposeDf        Elapsed time: 5.25322
gStossCalc    Elapsed time: 246535
gTransposeDfInverse   Elapsed time: 7.51981
gClearStoss         gClearStoss        Elapsed time: 0.216192
gTransposeDf        Elapsed time: 5.25834
gStossCalc    Elapsed time: 246533
gTransposeDfInverse   Elapsed time: 7.46163
gClearStoss         gClearStoss        Elapsed time: 0.216544
gTransposeDf        Elapsed time: 5.25523
gStossCalc    Elapsed time: 246538
gTransposeDfInverse   Elapsed time: 7.49238
gClearStoss         gClearStoss        Elapsed time: 0.215904
gTransposeDf        Elapsed time: 5.24982
gStossCalc    Elapsed time: 246536
gTransposeDfInverse   Elapsed time: 7.52288
real  24m47.123s
user  24m45.149s
sys   0m0.944s
```

25,165,824
grid nodes
in phase space

every loop handles
4,194,304 grid nodes
in phase space

(2 GPU)

```
NG=2    gCalculateParams      Elapsed time: 1.53939
NG=2    gCalculateParams      Elapsed time: 1.49997
gClearStoss        gClearStoss        Elapsed time: 0.211264
gClearStoss        gClearStoss        Elapsed time: 0.19552
gTransposeDf       Elapsed time: 5.2217
gTransposeDf       Elapsed time: 5.23258
gStossCalc    Elapsed time: 248925
gStossCalc    Elapsed time: 248926
gTransposeDfInverse   Elapsed time: 7.48387
gTransposeDfInverse   Elapsed time: 7.48378
gClearStoss        gClearStoss        Elapsed time: 0.200736
gClearStoss        gClearStoss        Elapsed time: 0.209472
gTransposeDf       Elapsed time: 5.2145
gTransposeDf       Elapsed time: 5.22477
gStossCalc    Elapsed time: 248722
gStossCalc    Elapsed time: 248723
gTransposeDfInverse   Elapsed time: 7.51037
gTransposeDfInverse   Elapsed time: 7.51152
gClearStoss        gClearStoss        Elapsed time: 0.199392
gClearStoss        gClearStoss        Elapsed time: 0.208352
gTransposeDf       Elapsed time: 5.21789
gTransposeDf       Elapsed time: 5.22787
gStossCalc    Elapsed time: 248926
gStossCalc    Elapsed time: 248926
gTransposeDfInverse   Elapsed time: 7.51379
gTransposeDfInverse   Elapsed time: 7.51504
real  12m35.874s
user  12m33.123s
sys   0m1.628s
```

25,165,824
grid nodes
in phase space

every loop handles
4,194,304 grid nodes
in phase space

two-times speedup
vs. 1 GPU

(3 GPU)

```
NG=3     gCalculateParams      Elapsed time: 1.47718
NG=3     gCalculateParams      Elapsed time: 1.53101
NG=3     gCalculateParams      Elapsed time: 1.5304
gClearStoss         gClearStoss         Elapsed time: 0.140192
gClearStoss         gClearStoss         Elapsed time: 0.155264
gClearStoss         gClearStoss         Elapsed time: 0.124384
gTransposeDf        Elapsed time: 4.94176
gTransposeDf        Elapsed time: 5.1377
gTransposeDf        Elapsed time: 5.14787
gStossCalc    Elapsed time: 164576
gStossCalc    Elapsed time: 164589
gStossCalc    Elapsed time: 164590
gTransposeDfInverse   Elapsed time: 7.12509
gTransposeDfInverse   Elapsed time: 7.43171
gTransposeDfInverse   Elapsed time: 7.44042
gClearStoss         gClearStoss         Elapsed time: 0.128416
gClearStoss         gClearStoss         Elapsed time: 0.13792
gClearStoss         gClearStoss         Elapsed time: 0.147904
gTransposeDf        Elapsed time: 4.93661
gTransposeDf        Elapsed time: 5.13046
gTransposeDf        Elapsed time: 5.13981
gStossCalc    Elapsed time: 164575
gStossCalc    Elapsed time: 164590
gStossCalc    Elapsed time: 164591
gTransposeDfInverse   Elapsed time: 7.11542
gTransposeDfInverse   Elapsed time: 7.44173
gTransposeDfInverse   Elapsed time: 7.4505
real  5m38.815s
user5m36.017s
sys  0m1.800s
```

25,165,824
grid nodes
in phase space

every loop handles
4,194,304 grid nodes
in phase space

superlinear speedup:

aprox 5-times (not 3 !) speedup
vs. 1 GPU