The extension of DVM-system to solve the problems with intensive irregular memory access

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The class of problems with irregular memory access

- Graph problems;
- Sparce matrices;
- Scientific and technical calculation on irregular grids.

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- Graph problems;
- Sparce matrices;
- Scientific and technical calculation on irregular grids.

They can use the same data format, for example, CSR

Programs with regular access to the memory

Problems:

- A single grid step in the computational domain – no flexibility, impossibly high demands on memory and processing power during grinding;
- Implementation of numerical methods are often tied to the form of a grid - two-dimensional, three-dimensional, cartesian, cylindrical, etc. So we can not replace geometry.

Positive sides:

- Neighborhood relations and spatial coordinates are not stored explicitly – memory saving;
- There is a simple accesses to arrays with constant shifts – freedom for a compiler optimizations, clarity for parallelization (including automatic parallelization).

Programs with irregular access to the memory

Positive sides:

- We can choose any mesh grinding – maintaining degree of grinding in parts of the area;
- Good opportunities for reuse of computing code, the freedom to choose the form of computational areas.

Problems:

- Neighborhood relations and spatial coordinates to be stored explicitly;
- Indirect indexing on arrays accesses – a barrier for a compiler optimizations, the complexity of parallelization (particularly automatic).

```
double A[L][L];

double B[L][L];

int main(int argc, char *argv[]) {
    for(int it = 0; it < ITMAX;  it++) {

        {

            for (int i = 1; i < L - 1; i++)
                for (int j = 1; j < L-1; j++)
                    A[i][j] = B[i][j];


            for (int i = 1; i < L - 1; i++)
                for (int j = 1; j < L - 1; j++)
                    B[i][j] = (A[i - 1][j] + A[i + 1][j] + A[i][j - 1] + A[i][j + 1]) / 4.;
        }
    }
   FILE *f = fopen("jacobi.dat", "wb");

   fwrite(B, sizeof(double), L * L, f);
   fclose(f);
   return 0;
}
```

Jacobi algorithm

```
#pragma dvm array distribute[block][block], shadow[1:1][1:1]
double A[L][L];
#pragma dvm array align([i][j] with A[i][j])
double B[L][L];

int main(int argc, char *argv[]) {
    for(int it = 0; it < ITMAX;  it++) {

        {

            for (int i = 1; i < L - 1; i++)
                for (int j = 1; j < L-1; j++)
                    A[i][j] = B[i][j];


            for (int i = 1; i < L - 1; i++)
                for (int j = 1; j < L - 1; j++)
                    B[i][j] = (A[i - 1][j] + A[i + 1][j] + A[i][j - 1] + A[i][j + 1]) / 4.;
        }
    }
   FILE *f = fopen("jacobi.dat", "wb");

   fwrite(B, sizeof(double), L * L, f);
   fclose(f);
   return 0;
}
```

Jacobi algorithm in the DVMH model

```
#pragma dvm array distribute[block][block], shadow[1:1][1:1]
double A[L][L];
#pragma dvm array align([i][j] with A[i][j])
double B[L][L];

int main(int argc, char *argv[]) {
    for(int it = 0; it < ITMAX; it++) {

        {
          #pragma dvm parallel([i][j] on A[i][j])
          for (int i = 1; i < L - 1; i++)
             for (int j = 1; j < L-1; j++)
                A[i][j] = B[i][j];

          #pragma dvm parallel([i][j] on B[i][j]), shadow_renew(A)
          for (int i = 1; i < L - 1; i++)
             for (int j = 1; j < L - 1; j++)
                B[i][j] = (A[i - 1][j] + A[i + 1][j] + A[i][j - 1] + A[i][j + 1]) / 4.;
        }
    }
   FILE *f = fopen("jacobi.dat", "wb");

   fwrite(B, sizeof(double), L * L, f);
   fclose(f);
   return 0;
}
```

Jacobi algorithm in the DVMH model

```
#pragma dvm array distribute[block][block], shadow[1:1][1:1]
double A[L][L];
#pragma dvm array align([i][j] with A[i][j])
double B[L][L];

int main(int argc, char *argv[]) {
    for(int it = 0; it < ITMAX;  it++) {
        #pragma dvm region inout(A, B)
        {
          #pragma dvm parallel([i][j] on A[i][j])
          for (int i = 1; i < L - 1; i++)
             for (int j = 1; j < L-1; j++)
                A[i][j] = B[i][j];

          #pragma dvm parallel([i][j] on B[i][j]), shadow_renew(A)
          for (int i = 1; i < L - 1; i++)
             for (int j = 1; j < L - 1; j++)
                B[i][j] = (A[i - 1][j] + A[i + 1][j] + A[i][j - 1] + A[i][j + 1]) / 4.;
        }
    }
   FILE *f = fopen("jacobi.dat", "wb");
   #pragma dvm get_actual(B)
   fwrite(B, sizeof(double), L * L, f);
   fclose(f);
   return 0;
}
```

Jacobi algorithm in the DVMH model

Programming tools

C-DVMH = C language + pragmas

Fortran-DVMH = Fortran 95 + pragmas

- Pragmas are high-level specification of parallelism in terms of a sequential program;
- There are no low-level data transfer and synchronization in the program code;
- Sequential programming style;
- Pragmas are "invisible" for standard compilers;
- There is only one instance of the program for sequential and parallel calculations.

Specifications of the parallel execution

- The distribution of arrays between the processors (distribute / align directives);
- Distribution of loop iterations between computing devices (parallel directive);
- Specification of parallel tasks and their mapping to the processors (task directive);
- The effective remote access to data located on other computing devices (shadow / across / remote specifications).

Specifications of the parallel execution

- The effective execution of reduction operations (reduction specification: max/min/sum/maxloc/minloc/…);
- Determination of the program fragments (regions) for execution on accelerators and multi-core CPU (region directive);
- Motion data control between the CPU memory and GPU memory (actual / get_actual directives).

DVM-system components

- Fortran-DVMH compiler;
- C-DVMH compiler;
- DVMH Run Time System;
- DVMH-программ debugger;
- Performance analyzer.

Use of DVMH in MPI-program: reasons

- There are a great foundation and experience of writing parallel programs for clusters;
- DVMH model suggests parallelizing sequential programs;
- The user does not want to give up their parallel program;
- DVMH model does not apply to parallelize some programs (eg, with random access memory).

Use of DVMH in MPI-program: results

- A new mode of DVM-system was addewd locally in each process;
- Undistributed parallel loop construction was added;
- Incremental parallelism and fast evaluation of DVMH-model of the CPU and GPU threads become available;
- Ability to use DVMH-parallelization become available inside the cluster node in the MPI-programs.

Use of DVMH in MPI-program: experience

- Solver with explicit scheme is the part of large developed set of computation programs:
  - C++, 39 000 LOC, templates, polymorphism, etc;

- Local modifications of the one module (~3000 lines) have been made, which are reduced to the addition about 10 DVMH directives;
- We were obtained the accelerations:
  - 2 CPU Intel Xeon X5670 (6 cores on each CPU – **9.8x**;
  - GPU NVidia GTX Titan (Kepler) – **18x**.

New rules for distribution

- Indirect distribution:

```
distribute A[indirect(B)]
```

- Derived distribution:

```
distribute A[derived([cells[i][0]:
          cells[i][2]] with cells[@i])]
```

New shadow edges

- Shadow edges are the set of elements that are not owned by the current process;

- New directive for inderect distribution:
  shadow_add`(nodes[neigh[i][0]:neigh[i][numneigh[i]-1] with nodes[@i]] = neighbours)`

The transition to a local indexing

- The procedure for the convert of the global (initial) index to the local (for direct memory access) <u>is too long</u>;

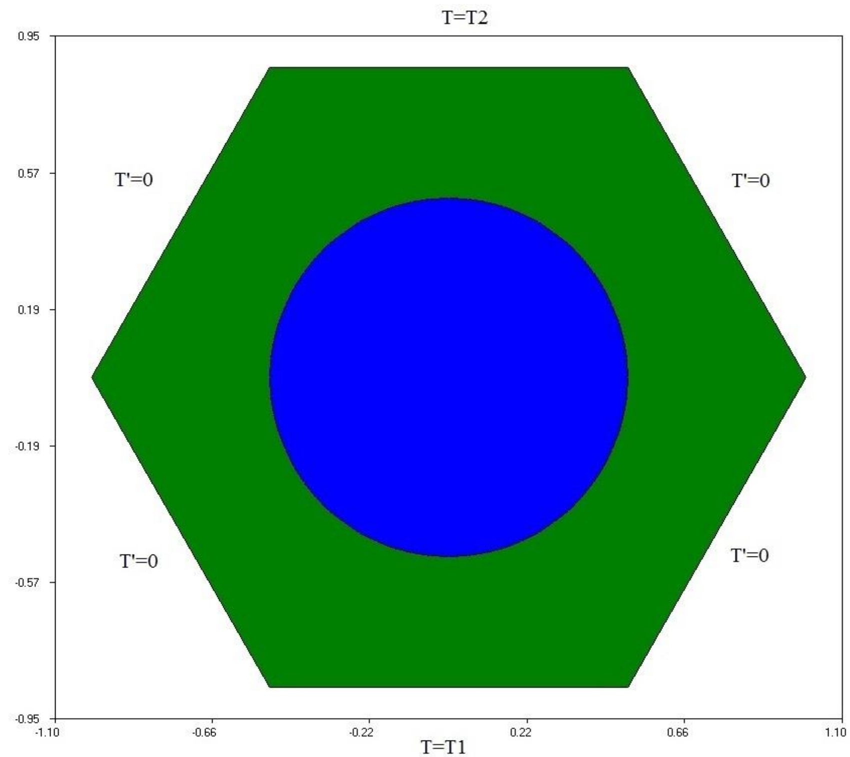
- For regular distributions the global and local indexes are the same;

- The executable directive was introduced for localization arrays indexes for indirect distributions:
  ```
  localize(neigh => nodes[:])
  ```

The test problem

- Two-dimensional heat conduction problem with a constant but discontinuous coefficient in the hexagon.

- The area consists of two materials with different coefficients of thermal.

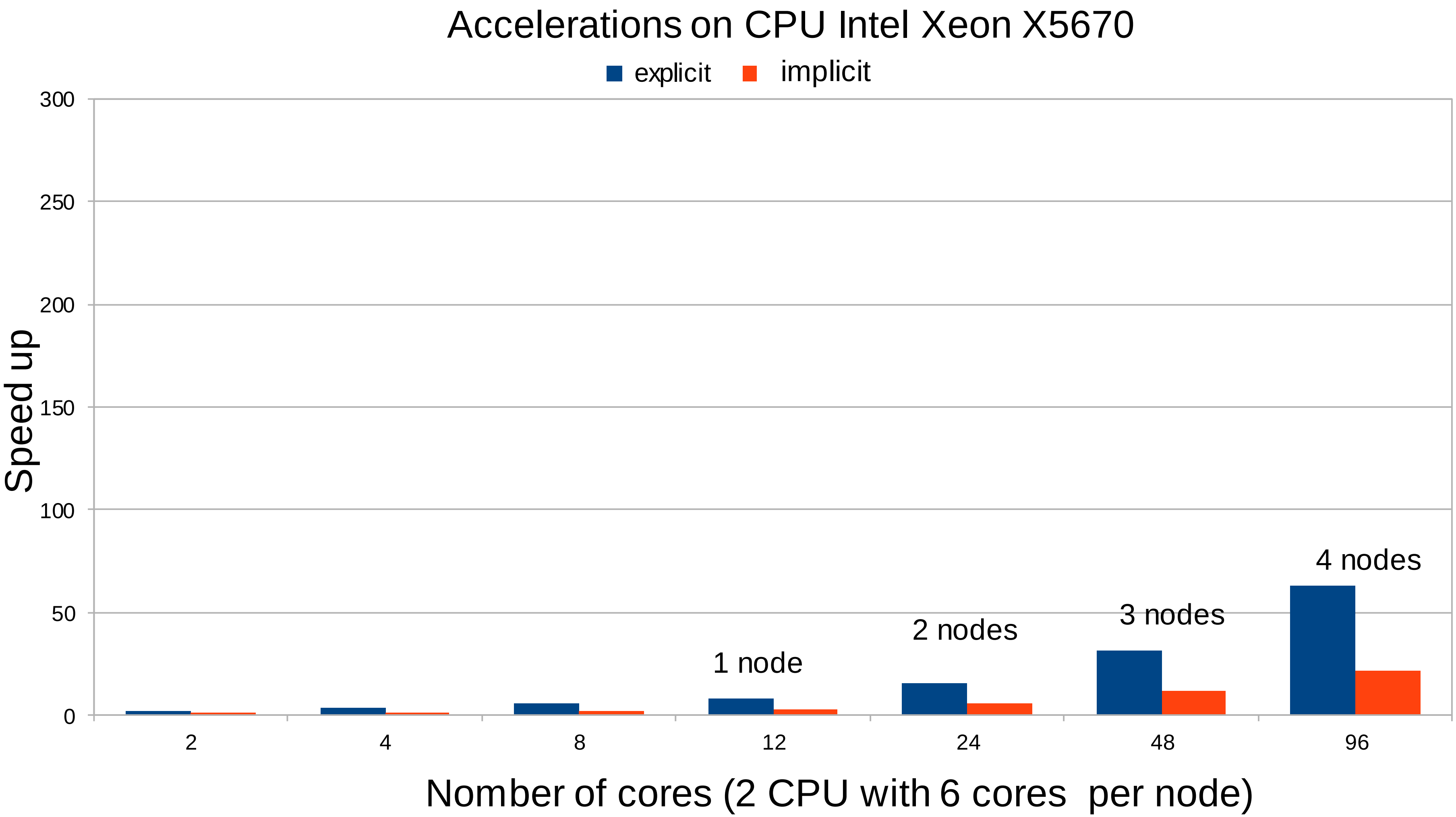


The test problem

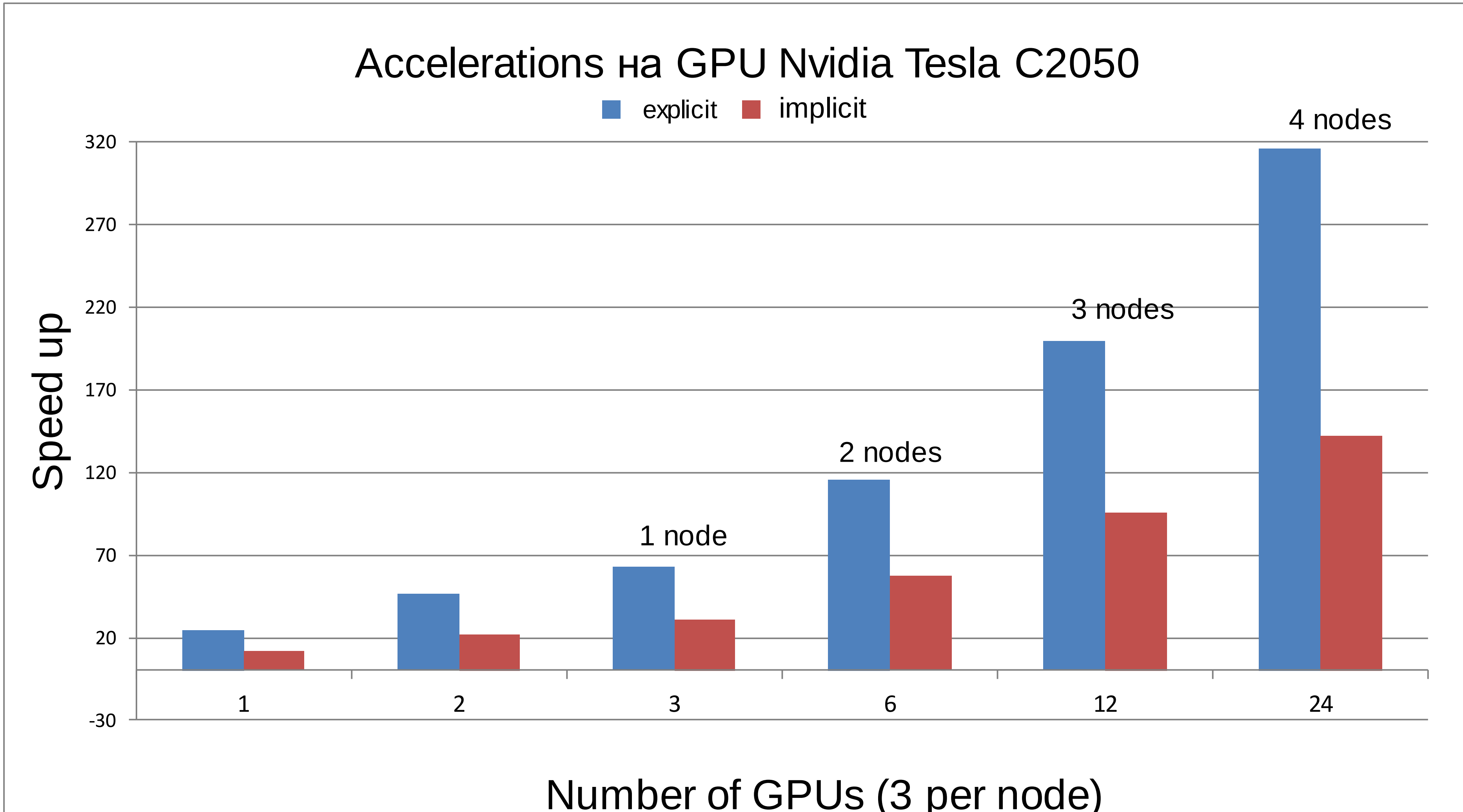
- Arrays are one-dimensional – **tt1,tt2**
- Variable number of "neighbors" – **ii**
- Links are specified by array – **jj**

```
do i = 1, np2
  nn = ii(i)
  nb = npa(i)
  if (nb.ge.0) then
    s1 = FS(xp2(i),yp2(i),tv)
    s2 = 0d0
    do j = 1, nn
      j1 = jj(j,i)
      s2 = s2 + aa(j,i) * tt1(j1)
    enddo
    s0 = s1 + s2
    tt2(i) = tt1(i) + tau * s0
  else if (nb.eq.-1) then
    tt2(i) = vtemp1
  else if (nb.eq.-2) then
    tt2(i) = vtemp2
  endif
  s0 = (tt2(i) - tt1(i)) / tau
  gt = DMAX1(gt,DABS(s0))
enddo
do i = 1, np2
  tt1(i) = tt2(i)
enddo
```

Results, 8 million nodes



Results, 8 million nodes



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