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;
- Sparse matrices;
- Scientific and technical calculation on irregular grids.
The class of problems with irregular memory access

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

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

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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++)

    }

    FILE *f = fopen("jacobi.dat", "wb");

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

    FILE *f = fopen("jacobi.dat", "wb");

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

Jacobi algorithm in the DVMH model

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#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++)
    }

    FILE *f = fopen("jacobi.dat", "wb");
    fwrite(B, sizeof(double), L * L, f);
    fclose(f);
    return 0;
}
#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++)
        }
    }
    FILE *f = fopen("jacobi.dat", "wb");
    #pragma dvm get_actual(B)
    fwrite(B, sizeof(double), L * L, f);
    fclose(f);
    return 0;
}
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.

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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 (e.g., with random access memory).
Use of DVMH in MPI-program: results

- A new mode of DVM-system was added 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.

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New rules for distribution

- **Indirect distribution:**

  \[
  \text{distribute } A[\text{indirect}(B)]
  \]

- **Derived distribution:**

  \[
  \text{distribute } A[\text{derived}([\text{cells}[i][0]:\text{cells}[i][2]] \text{ with } \text{cells[@i]}])]
  \]

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New shadow edges

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

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

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The transition to a local indexing

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

- 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 – \textbf{tt1,tt2}

- Variable number of "neighbors" – \textbf{ii}

- Links are specified by array – \textbf{jj}

\begin{verbatim}
    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
\end{verbatim}
Results, 8 million nodes

Accelerations on CPU Intel Xeon X5670

- **explicit**
- **implicit**

Number of cores (2 CPU with 6 cores per node)

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Results, 8 million nodes

Accelerations на GPU Nvidia Tesla C2050

- Speed up
- Number of GPUs (3 per node)

Explicit vs Implicit Accelerations
- Explicit
- Implicit

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