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Elaboration of applied software for high–productive multiprocessor systems on the basis of transputer

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Abstract

In this work a parallel algorithm for the problem of thermo–elastic–plastic flow of the medium which occurs of high–velocity loading, has been built; problems, occurring when choosing the topology of transputer network and its balancing have been studied

To solve the modern problems which, to a certain extent, determine the scientific and technical progress, as well as for conducting fundamental research, we need computers whose capacity is ten and hundreds of billion operations per second. Such capacity is needed in connection with the growing complexity of problems, as well as with the increased demands towards the utilization of mathematical models. It is becoming a norm to use high dimension mathematical models on networks thus allowing to reveal the fine effects of investigated phenomena. On the basis of Intel, Motorolla, etc. successive processors, the state of the modern element base does not allow to achieve the required capacity.

The way out in this situation is the creation of multiprocessor computer systems on the basis of transputer technologies with wide multisequencing of calculations. The capacity increase of such systems can be provided both by increasing the capacity of a separate element — the transputer and the increase of their number in the system. The principal hardship in realizing this approach is the need to assure the increase of capacity of the multitransputer system along with increasing

the degree of parallelism in information processing and in regulating the iniformity of loading separate elements of the system.

Effective use of all multi–processor systems possibilities can occur only at corresponding adaptation of software and the elaboration of new numerical algorithms with account for possibilities and peculiarities of parallel calculations. Let us give a more interaction between the structure of mathematical algorithms and the architecture of multi–processor computer systems for achieving an effective multisequencing and balancing (loading degree) of such systems separate elements.

The list of references on the realization of numerical algorithms for some classes of problems on multi–transputer systems has been actively enriched lately [1–9]. It is due to more intensive utilization of multi–processor systems at leading research centres.

As a rule, the problems of mathematical physics have an inner parallelism. Nevertheless, the character and degree of multisequencing depends upon the stage of problem solution at which this multisequencing occurs. Besides, the quantity of simultaneously working transputers as well as the technology, i.e. the character of elements interconnection, depend on the same factor. The multisequencing stages should correspond to the levels of gradual decomposition of the initial problem into smaller hierarchically subordinated parts.

We shall present herewith the decomposition levels that are similar to those adopted in literature [1,5].

The first decomposition levels is the division of the initial problem into several subproblems. They can be several versions of the same problem differing by the set of initial data. The achieved multisequencing degree is not big, about 10^1.

The second decomposition level is the division of separate sub–problems into many uniform procedures carried out simultaneously at various initial data. For problems of mathematical physics thus type of parallelism is called geometrical parallelism. It is achieved by dividing the initial designed field into several sub–fields and their distributions on different processors. In this case the multisequencing degree can reach $10^2 - 10^3$.

The third level of decomposition is the multisequencing of sepa-

rate procedures, e.g. the conversion of matrixes, calculation of Fourie transformation, etc. The multisequencing degree varies from 10^0 to 10^3.

The most profound as well as the most laborious is the fourth decomposition level which consist in parallel accomplishing of various stages of arithmetic expressions' calculation. The multisequencing degree does not exceed 10^1.

When applying the available numerical methods to multitransputer systems the most accessible and natural is the second decomposition level — the geometrical decomposition and, within the limits of the possible, the third level. A rather fine question of geometrical multisequencing is the problem concerning the number of sub–fields into which the initial designed field is divided. The number of accessible processors serves as restriction in principle, one can practically organize any number of parallel processes in one transputer, but this is quasimultisequencing since in on transputer they will be served by the priority scheduler depending upon the level of problem priority and the degree of its readiness.

When a sufficiently large number of transputers is available the division degree is not restricted. The initial field can be divided is such a way that each node of the designed net could be calculated on its transputer. However, a problem occurs which is due to the fact that the quantity of information necessary to be transmitted from one node to another will be commensurable with the number of operations performed by this transputer. And since the speed of information transmission is considerably lower than the speed of performing arithmetical and logical operations, the general fast–acting of the computer system is lost.

From this point of view we shall analyze the available algorithms for solving problems of mathematical physics. For their successful and effective multisequencing it is necessary that the utilized algorithms meet the following requirements:

a. It is necessary to meet the requirement of locality interaction between spatial nodes of the used differential scheme and thus, between processors of the computer system. The term locality

interaction means that in the computation process such template of the differential scheme is used that data exchange occurs mainly between neighbors or in the nearest topological neighborhood nodes. From this point of view the most effective are the explicit two– or three–layered algorithms of net equations solutions. Besides, effective are the iterational methods which, by ideas, are close to explicit schemes [10,11].

b. Comparative regularity of data exchange between nodes of the differential scheme. This requirement is met by dividing the initial field into an aggregate of sub–fields covered by regular nets and consisting, for instance, only of convexed polygons. This property is also true for a wide circle of problems both in Eiler and Lagrange statements [5,12].

c. The requirement to maintain optimum correlations between the number of designed operations on each processor of the system and volume of information transmitted to the neighboring nodes.

d. Effective dynamical balancing of the transputer system, i.e., the uniform loading, of all processors in the operation process. The theory of priorities and queues should find successful application here.

To a certain degree, all aforesaid requirements are met by homogeneous explicit differential schemes and through count schemes which allow to carry out calculations according to uniform formulae in all the designed field.

As an example of multisequencing we shall consider the problem of high–velocity penetration of anti–meteorite defence with impact speed ranging between 1–20 km/s. The interest to such problems has been born by the growing choking up of the terrestrial space and thus by the growing danger of collision between part of worn–out satellites or last stages of carrier rockets and operating space objects. The proposed calculation method allows to obtain the process of fragments deformation during inter–collision. Processes of crater formation, appearance

of zones of melted and vaporized substance, distribution of the initial indentor impulse on axial and radial components of the target [15] should be investigated. Statement of the problem and the method for numerical solution are given in [13,15].

Strong shock waves occur in the indentor and the target during collision at high–velocity strike. The density of energy flow behind the fronts of such waves may lead to partial or total melting of the target and indentor substance. After attenuation of the shock wave and of its reflection from free surfaces, a straining stress occurs which can cause chipping–of. A crater with characteristic edges formes on the face of the target.

To describe all stages of the surveyed process, it is necessary to have the state equation which provides detailed information in a wide field of parameters including the melting zones, as well as the information about strength and rheological properties of the investigated substance.

The system of equations describing the movement of the substance in two–dimensional, axially symmetric statement looks as follows:

$$\frac{\partial \rho}{\partial t} = \frac{\partial(\rho u)}{\partial r} - \frac{\partial(\rho v)}{\partial z} - \frac{\rho u}{r}, \tag{1}$$

$$\frac{\partial(\rho u)}{\partial t} = -\frac{\partial P}{\partial r} + \frac{\partial s_{rr}}{\partial z} + \frac{\partial s_{rz}}{\partial z} + \frac{s_{rr} - s_{\theta\theta}}{r}, \tag{2}$$

$$\frac{\partial(\rho v)}{\partial t} = -\frac{\partial P}{\partial z} + \frac{\partial s_{zz}}{\partial z} + \frac{\partial s_{zr}}{\partial r} + \frac{s_{rz}}{r}, \tag{3}$$

$$\frac{\partial(\rho E)}{\partial t} = -\frac{P}{\rho}\frac{\partial \rho}{\partial t} + s_{rr}\frac{\partial u}{\partial r} + s_{zz}\frac{\partial v}{\partial z} + s_{\theta\theta}\frac{u}{r} + s_{rz}(\frac{\partial u}{\partial z} + \frac{\partial v}{\partial r}), \tag{4}$$

Here ρ — is the density, $\{u, v\} = \vec{w}$ — are the components of the velocity vector, P is the hydrostatic pressure, $\sigma_{i,j} = -P\delta_{i,j} + s_{i,j}, i, j$ — assume values r, z, θ, E is the specific inner energy. The components of the deviator of tensor stresses are connected with the components of deformation velocities $\varepsilon_{i,j}$ as follows:

$$\dot{s}^{\nabla}_{zz} = 2\mu(\dot{\varepsilon}_{zz} + \frac{1}{3\rho}\frac{\partial\rho}{\partial t}),$$

$$\dot{s}^{\nabla}_{rr} = 2\mu(\dot{\varepsilon}_{rr} + \frac{1}{3\rho}\frac{\partial\rho}{\partial t}), \tag{5}$$

$$\dot{s}^{\nabla}_{\theta\theta} = 2\mu(\dot{\varepsilon}_{\theta\theta} + \frac{1}{3\rho}\frac{\partial\rho}{\partial t}),$$

Here ∇ means the derivate in Jauman's sense:

$$\dot{s}^{\nabla}_{ij} = \dot{s}_{ij} - s_{ik}\omega_{jk} - s_{jk}\omega_{ik},$$

$$\omega_{ij} = \frac{1}{2}(\frac{\partial v_i}{\partial x_j} - \frac{\partial v_j}{\partial x_i}). \tag{6}$$

v_i are the velocity vector components, x_j are the decart coordinates. The components of velocities deformation tensor is determined as follows:

$$\dot{\varepsilon}_{zz} = \frac{\partial v}{\partial z}; \dot{\varepsilon}_{rr} = \frac{\partial u}{\partial r}; \dot{\varepsilon}_{\theta\theta} = \frac{v}{r}; \tag{7}$$

$$\dot{\varepsilon}_{rz} = \frac{1}{2}(\frac{\partial u}{\partial r} - \frac{\partial v}{\partial z}), \tag{8}$$

We'll assume that the medium satisfies Mizes's plasticity criterion:

$$s^2_{rr} + s^2_{zz} + s_{rr}s_{zz} + s^2_{rz} \le \frac{2}{3}Y^2_0, \tag{9}$$

In equations (5)–(8) μ is the shift modulus, Y^2_0 is the dynamic limit of plasticity.

To close the system these equations are supplemented by state equations:

$$P = P(\rho, E).$$

For media that undergo great deformations good results are provided by the state equation of Grunaizen type in the form of [7]

$$P = k_1\kappa + k_2\kappa^2 + k_3\kappa^3 + \gamma_0\rho_0 E, \quad \kappa = 1 - \frac{\rho_0}{\rho}. \tag{10}$$

Here ρ_0 is the initial density, k_1, k_2, k_3, γ_0 are the substance constants.

To determine the influence of strength properties of materials during late flowing stages we'll use Sheinberg–Guinan's model. In the latter the dynamic plasticity limit Y_0 and the shift modulus μ_0 depend on pressure, temperature and other state parameters:

$$Y = Y_0(1 + \beta\varepsilon_u^p)^n[1 - bP(\frac{\rho_0}{\rho})^{1/3} - h(T - T_0)],$$

$$Y_0(1 + \beta\varepsilon_u^p)^n \le Y_{max}, Y_0 = 0 \quad T > T_m,$$

$$T_m = T_{m0}(\frac{\rho_0}{\rho})^{2/3} exp(2\gamma_0(1 - \frac{\rho_0}{\rho})),$$

$$\mu = \mu_0(1 - bP(\frac{\rho_0}{\rho})^{2/3} - h(T - T_0)).$$

Here $\varepsilon_u^p = (2\varepsilon_{ij}^p/3)^{\frac{1}{2}}$ is the intensivity of the plastic deformations tensor; T_m is the temperature of materials melting; Y_0, Y_{max}, μ_0, T_{m0}, β, n, b, γ_0 are constant materials.

The temperature of the substance was calculated from the following equation:

$$T = (\frac{E}{\rho_0} - \varepsilon_0)/3R, \varepsilon_0 = \varepsilon_{00} + \varepsilon_{01}\kappa + \varepsilon_{02}\kappa^2 + \varepsilon_{03}\kappa^3 + \varepsilon_{04}\kappa^4, \tag{11}$$

where $R, \varepsilon_{00}, \varepsilon_{01}, \varepsilon_{02}, \varepsilon_{03}, \varepsilon_{04}$ are constants of materials.

The values of constants used in equations (9)–(10) for alluminium, which was chosen as material of the indentor and target, are borrowed from [7]:

$$\rho = 2780 \quad kg/m^3, \qquad \mu_0 = 27.6 \quad GPa,$$

$$Y_0 = 0.29 \quad GPa, \qquad Y_{max} = 0.68 \quad GPa,$$

$T_{m0} = 1220K, \qquad \beta = 125, \qquad b = 0.065 \quad GPa^{-1},$

$n = 0.1, \qquad h = 6.2 \cdot 10^{-4} K^{-1}, \qquad \gamma_0 = 1.97,$

$k_1 = 0.7906, \qquad k_2 = 1.325, \qquad k_3 = 2.13,$

$\varepsilon_{00} = -2.77 \cdot 10^{-3}, \qquad \varepsilon_{01} = -5.547 \cdot 10^{-3}, \qquad \varepsilon_{02} = 1.364 \cdot 10^{-1},$

$\varepsilon_{03} = 2.495 \cdot 10^{-1}, \qquad \varepsilon_{04} = 5.16 \cdot 10^{-1}.$

The boundary conditions are given as follows: on free surfaces of the target and indentor — the condition of equality to zero stress. On the contact boundary — the condition of continuity of velocity and stress: $u\mid_{-} = u\mid_{+}, \sigma\mid_{-} = \sigma\mid_{+}$.

Initial conditions:

for the indentor – $u = U_0, \rho = \rho_0, \sigma_{ij} = 0,$
for the target – $u = 0, \rho = \rho_0, \sigma_{ij} = 0.$

For numerical solution of the problem, the algorithm proposed in [12] is ised. The method of big particles with a corresponding modification is used in this algorithm. The proposed modification allows to eliminate the invariance of the method of big particles in relation to co-ordinates transformation. Besides, a special algorithm is introduced thus allowing to give and trace the contact and free boundaries on Eiler's network. The choice of such scheme is stipulated by the necessity to calculate the great deformations of the substance. Application of well known Lagrange methods does not allow to carry out calculations with great deformations due to strong distortions of the differential network.

The introduction of mobile boundaries on Eiler's network highly complicates the computer algorithm. Suffice it to note that the calculation of boundaries shift on the following time step takes about 65 effects as the formation of the crater's edge, formation of surfaces on chipping–off, etc. So it is supposed to supplement the existing program complex with the pure Lagrange method for calculating the later plasticity stages. Thus the calculation of the initial stage with great

deformations will be accomplished by the Eiler–Lagrange method; after lowering the stress and decreasing the deformation, the transition to the Lagrange network will occur along with the preservation of all plasticity peculiarities.

However, the calculation method used in this work allows to trace the process of crater formation, its change with time, to study the mechanism of formation of ejection matter on the target's face, to trace the formation and time development of those zones where the substance is in melting state.

The FORTRAN language is widely used in all branches of science and technology. Therefore it is necessary to look for effective methods of transferring the existing software to multiprocessor systems. The multitransputer systems maintain parallel FORTRAN version of INMOS and 3L Ltd. However, the use of only FORTRAN is often not enough since it doesn't provide an effective system for trasmitting messages to remote units of the transputer network; it doesn't envisage the procedure of direct appeal from any working transputer to the host–machine by–passing the root transputer (in our case the host–machine denotes the IBM PC computer in whose 16 digit nest the transputer plate is introduced).

The application of operational medium Fornet 3L (firm 3L Ltd.) allows to avoid these hardships [14]. In the Fornet 3L system the input–output standard procedures can be used in "master" programs performed on root transputers. An alternative input–output system has been elaborated for all other units of the network. It provides the possibility to realize from working transputers a formatted or non–formatted access to read–write files from any network unit.

Besides, for effective loading of all the transputer network, it is necessary to write the OCCAM program for loading this network. The topology of the transputer network can be realized as a ruler, chain of nodes, binary tree and can be extended to a two–dimensional or three–dimensional network. The same program is fulfilled on all transputers, except the root– transputer. Thus, the geometrical decomposition of designed two–dimensional field of variables (system of equations (1)–(11)) is realized.

The "master" program, which includes the "server" procedure assuring interface with the host–machine, is fulfilled on a root–transputer. The exchange system consist of a multiplexer–root–finder. It is connected with all "master" and "slave" programs and provides message transmission between units. In each "master" – "slave" programs there is the subroutine user which contains a user sub–program. In the simplest case the order of placing can be a chain of several transputers whose "1" and "2" links are interconnected, while "0" and "3" are free.

The "master" program consist of processes which will be carried out parallelly: the main process "worker" serving the "server" process, two input and two output processes. The "worker" process provides the standard interface with the multiplexor and the call of program "user". The "server" – "worker" processes must have the possibility to place the information on the screen or in the file, as well as to get the information from the host–machine. However, any operation of removal from the working unit should pass through the "server" process.

Priority scheduler should consist of processes IN1, IN2, OUT1, OUT2 and of the input–output sub–program which is a standard procedure of Fornet. The text of program is written in 3L FORTRAN and it provides the possibility to compile and configurate them using the MS–DOS command files.

The command files which permit to compile and link the "master" and "slave" programs will look as follows:

t8f ZOND

linkt ZOND.LNK, MASTER.B4

file ZOND.LNK must consist

ZOND.BIN

$\backslash FORT\backslash mrouter.bin$

$\backslash FORT\backslash server.bin$

$\backslash FORT\backslash iosub.bin$

$\backslash FORT\backslash frtl8.bin$

$\backslash FORT\backslash move - t8.bin$

$\backslash FORT\backslash memcopy.bin$

$\backslash FORT\backslash taskharn.bin$

After fulfilling the ZOND program of the multiplexor for "master" – *mrouter.bin*, the "server" program Fornet input–output library program, the run–time library FORTRAN will be linked.

Similar command files can be created for compilation and linking with the multiplexor program for sub–program (*srouter.bin*)

Program ZONDS.B4 must be realized on all transputers except the root one on which program ZONDM.B4 is realized, as well as the last one which program ZONDL.B4 is realized.

Programs ZONDM.B4, ZONDM.B4 and ZONDL.B4 should be configurated for a chain of n transputers. For this we'll write the command file CONFN.BAT.

The configurated file fr4.cfg is written in OCCAM. For the sake it certainty let us choose the number of transputers as $n = 4$. In the file fr4.cfg it is necessary to define the logical names for transputers, links connection, the mode of placing the programs on processors, etc.

After configuration, file ZOND4.APP is obtained which may be realized by RUN ZOND4 command, where file RUN.BAT: afserver -:b %1.app.

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