Domain coupling with the DOVE scheme

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Distributed data processing and utilization of the capacity of clusters of workstations have become increasingly important in the area of CFD in general and in modeling of multi-component systems in particular. This is usually accomplished by means of domain decomposition technique. A standard approach to domain decomposition for elliptic problems [1,2] consists in splitting the whole physical domain into separate regions, or sub-domains, constructing computational grids on each of the sub-domain and combining them together using two-way interprocessor communications.

Figure 1 shows a typical inter-domain "sewing" using two-nodes overlap which will provide continuity in the solution and it's first order derivatives, thereby preserving the accuracy of first-order discretization schemes. For a higher-order accurate scheme a bigger overlap will be required, generally 2**k* nodes long, where *k* is the required accuracy of the discretization scheme. When the alignment of the overlapping sub-grids from of different sub-domains is exact, as is in Fig. 1, we have the case of a conformal mapping, which requires no interpolation of communicated variables, and therefore, preserves the order of accuracy as discussed above.

When domain decomposition is applied to an unstructured mesh the realization of conformal mapping will often lead to highly irregular boundaries for each sub-domain, which in turn will create extra errors in the gradient approximations. One possibility to avoid this is to construct all parallel domains independently and then combine them together using inter-domain interpolation. This approach is conceptually simple and can be used to construct domains of fairly complex topologies. It naturally provides for smooth boundaries of each sub-domain. The price for this convenience is in the extra computational effort required to do variables interpolation at the communication boundaries. Considering the bottom-up approach of this technique in contrast to top-down approach of a conventional domain decomposition we call it *domain coupling* rather than decomposition.

Figure 2 shows an example of the domain coupling for unstructured meshes, using four communication planes. As can be seen in the figure the positions of the nodes in both grids do not necessarily coincide in the region of overlap. This coupling scheme was implemented into an automatic domain overlap identification and coupling procedure DOVE, used in a multi-domain multi-physics solver MulPhys[1] [3].

The procedure consists of the initialization and interpolation steps. The initialization step is used to determine for each domain the regions of overlap with other domains, and to set the connectivity arrays pointing from the overlapped boundary nodes to the corresponding internal cells of the overlapping domain. The interpolation procedure is called from the flow solver whenever the values of the overlapped boundary variables need to be updated with the corresponding interpolated values from the parallel domain.

In order to establish the connectivities the array of boundary coordinates of each domain is sent to all other domains, and the corresponding arrays are received from other domains. Each received boundary point is analyzed on whether it is inside of the current domain, and if so, the mesh-cell (tetrahedron) of the current domain is found, which hosts the boundary point.

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Both the coordinates of the points and the host-cell indexes are stored for a subsequent inter-domain communication in the interpolation step.

During the inter-domain communication initiated by the solver the values of the dependent variables are interpolated to the boundary points of the overlapping domains stored in the previous step. Then the interpolated values are sent to the overlapping domains. The corresponding interpolated variables are received from the overlapping domains, and are used to update the variables on the overlapped boundary.

An example in Fig. 3 shows a complex domain composed of two overlapping domains: a straight and a curved pipe. A fluid flow was simulated in this domain by specifying a pressure drop between the inlet and the outlet of the straight pipe domain. Domain coupling with the DOVE scheme enabled to simulate the continuous flow passage through the composite domain with deflection of some of the flow from the straight pipe to the curved one (Fig. 4).

This scheme can be easily extended to handle dynamic overlapping regions, when the domains may change shape or move with respect to each other. In this case the appropriate DOVE functions should be called from within the main continuum solver with the pre-defined time intervals to update the changing geometry of the overlap region and re-generate the connectivity arrays.

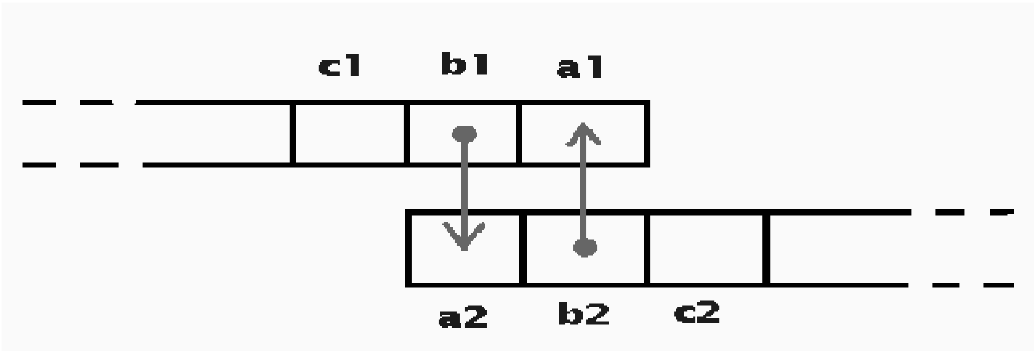

Fig. 1. Domain decomposition on co-located grids.

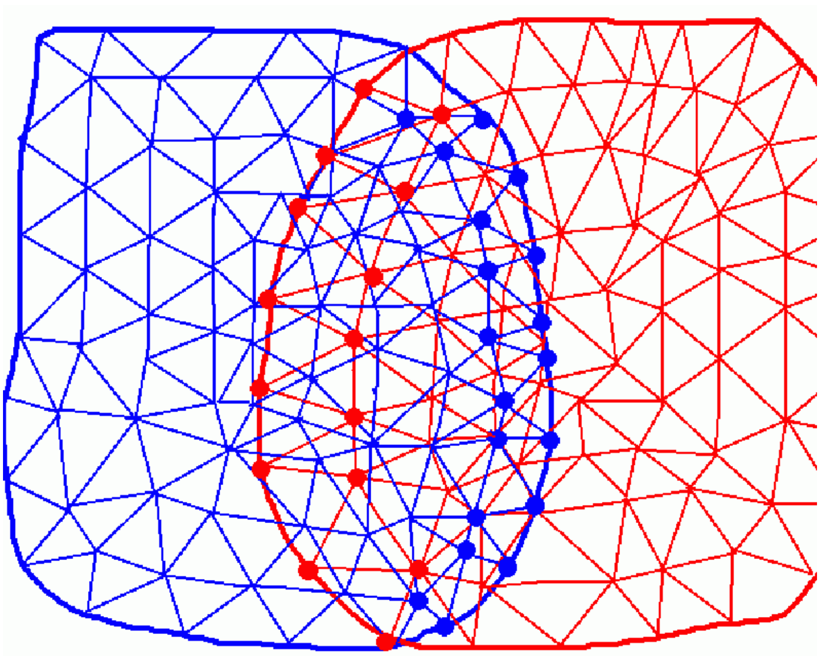

Fig. 2. Domain decomposition on overlapping unstructured grids.
ICB-nodes are marked with thick dots.

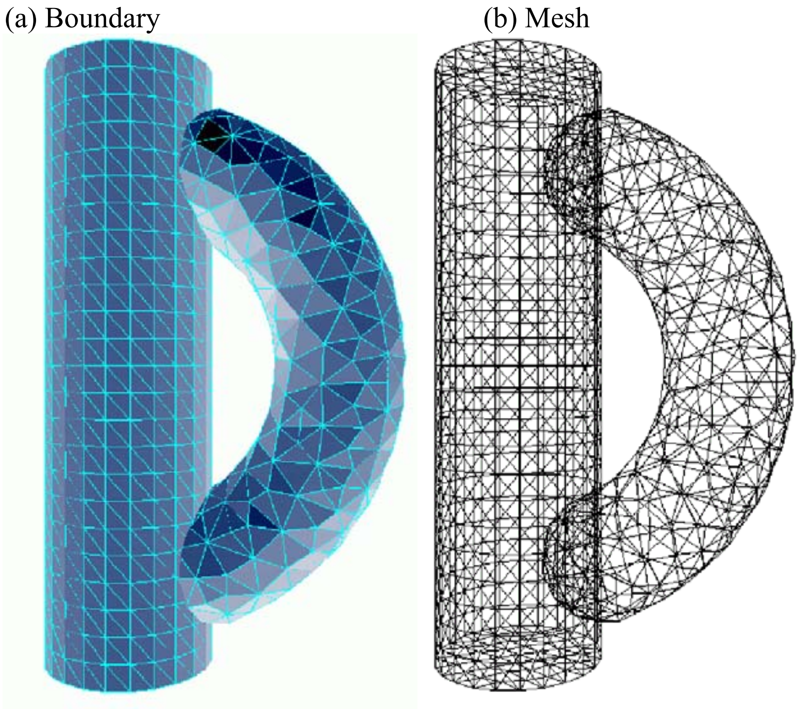

Fig. 3. Domain coupling.

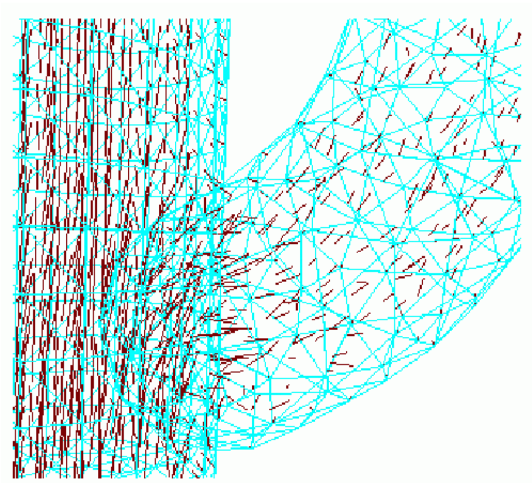

Fig. 4. Flow through the coupled domains.
A simulation is available at www.mulphys.com/dove.

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