

Face Selectors

Thomas Bendall

1 Overview

The LFRic infrastructure is designed to loop over columns, allowing efficient vectorisation and parallelisation across the horizontal domain. However, some physics kernels need to operate on horizontal faces (edges) rather than cell centres. Since faces are shared between two adjacent columns, we face a computational challenge: each face is adjacent to two columns, and we must ensure that the face computation is performed only once, not twice.

Face selector fields provide the solution to this problem. They consist of two 2D fields:

1. **East-West (E/W) face selector:** indicates which east or west faces in each column should be computed
2. **North-South (N/S) face selector:** indicates which south or north faces in each column should be computed

These selectors contain information about which faces in each column should be included in the computation, ensuring that every face is computed exactly once as the kernel loops over all columns. This approach maintains the column-based loop structure while correctly handling faces through careful domain decomposition.

2 Old Method

2.1 Face Selector Field Interpretation

In the old method, face selector fields take integer values of 1 or 2, with the following interpretation:

Face Selector Value	E/W Field Meaning	N/S Field Meaning
1	Compute the west face only	Compute the south face only
2	Compute both west and east faces	Compute both south and north faces

Table 1: Interpretation of face selector field values in the old method.

Therefore, summing the face selector field values over all columns gives the total number of faces that will be computed in each column. This is illustrated by the diagram below:

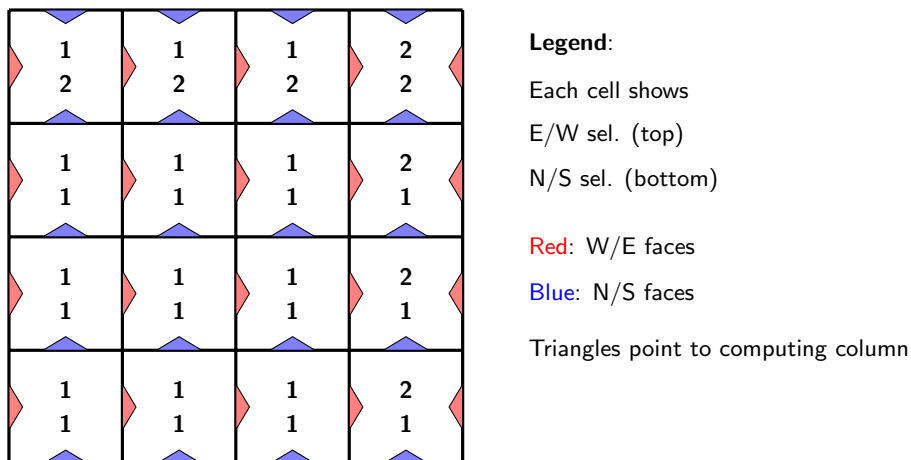


Figure 1: Illustration of face selection across a 4x4 column grid. Each cell centre displays two values: the E/W face selector (top) and the N/S face selector (bottom). Red triangles indicate west/east faces and blue triangles indicate south/north faces. Triangle bases lie on the face edge with the apex pointing towards the column that will perform the computation for that face.

2.2 Generation of Face Selector Fields

The face selector fields are generated through a two-pass algorithm:

1. **First pass:** Initialize both E/W and N/S face selector fields to 1 everywhere. Loop over all columns and increment the counter for each face indicated by the current face selector values.
2. **Second pass:** Loop through all columns again, iterating over all faces in each column:
 - If a north or east face has already been incremented by an adjacent column, leave the face selector value at 1 for that face
 - If a north or east face has not yet been incremented, set the face selector to 2 in the current column, and increment the counter for that face

2.3 Issues with the Old Method

The old method has several limitations:

- **Double computation on cubed-sphere:** On cubed-sphere meshes, certain MPI decompositions (including single-process runs) result in some faces being computed twice, violating the single-computation requirement
- **Race conditions:** When multi-threading is enabled in MPI decompositions where faces are computed twice, non-deterministic results can occur due to race conditions in face computations
- **Halo region mismatch:** When not using annexed Degrees of Freedom (DoFs), MPI regions may not align properly across process boundaries, causing disagreement between neighbouring MPI regions
- **Incomplete coverage:** Face selector regions do not extend into halo regions, potentially leaving boundary computations incomplete

3 New Method

In the new method, the face selector fields are extended to take integer values of -1 , 0 , 1 , or 2 , allowing for a more flexible and correct assignment of faces to columns. The interpretation of each value is given in Table 2.

Face Selector Value	E/W Field Meaning	N/S Field Meaning
-1	Compute east face only	Compute north face only
0	Compute no E/W faces	Compute no N/S faces
1	Compute west face only	Compute south face only
2	Compute both west and east faces	Compute both south and north faces

Table 2: Interpretation of face selector field values in the new method.

With this definition, the sum of the *absolute values* of the face selector fields gives the total number of faces computed per column. The new method is illustrated in the diagram below. In this example, columns 0, 1, 2 and 3 have E/W selector values of 1, 2, -1 and -1 respectively, meaning the five vertical faces are each computed exactly once. Rows 0, 1, 2 and 3 have N/S selector values of 1, 2, -1 and -1 respectively, similarly covering all five horizontal faces exactly once.

3.1 Generation of Face Selector Fields

The face selector fields in the new method are generated by a single-pass algorithm:

1. Loop through all columns, and for each column loop over all faces.
2. If a given face has not yet been assigned to any column, assign it to the current column.
3. Once all faces have been assigned, determine the face selector values for each column based on the set of faces assigned to it, according to Table 2.
4. Values in halo regions are determined by repeating the same calculation for halo columns.

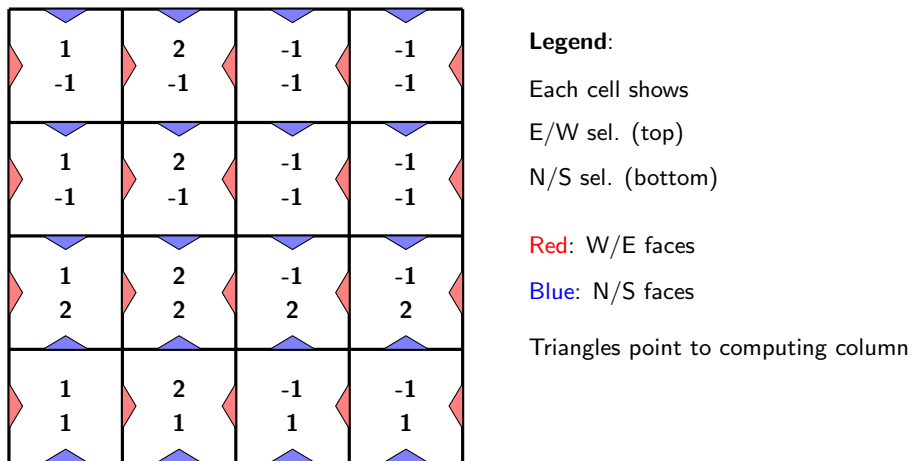


Figure 2: Illustration of face selection across a 4×4 column grid using the new method. Each cell centre displays two values: the E/W face selector (top) and the N/S face selector (bottom). The -1 values indicate columns/rows responsible for only an east or north face respectively. Triangle bases lie on the face edge with the apex pointing towards the column that will perform the computation for that face.