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# Proposal for C2y

N33xx

# Array Notation for Vectorization

 **Authors, affiliations:** Javier A. Múgica

 Martin Uecker, Graz University of Technology

## History

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## Table of contents

[1 Introduction](#_TOC000147)

[Intent of the feature](#_TOC000005)

Other languages

[Intent of the proposal](#_TOC000030)

[2 Selections [B:L], [B:L:s], [:] and [::]](#_TOC000031)

[Semantics of range selection](#_TOC000032)

[Continuous subarray selection](#_TOC000006)

[The type of A[B:L] for constant L](#_TOC000033)

[The type after lvalue conversion](#_TOC000034)

[The type of A[B:L] for nonconstant L](#_TOC000148)

[A variable length array](#_TOC000036)

[Mandatory VLA](#_TOC000009)

[The selection [::]](#_TOC000149)

[Stepped selections](#_TOC000150)

[s equal to zero](#_TOC000038)

[The kind of expressions allowed for B, L and s](#_TOC000151)

[3 Broken arrays](#_TOC000012)

[Array subscripting applied to an array with a selection](#_TOC000094)

[Array subscripting when the first dimension is broken](#_TOC000095)

[Margins](#_TOC000096)

[4 Relational operators and empty selections](#_TOC000047)

[Equality operators](#_TOC000107)

[0-dimensional selection](#_TOC000048)

[Relational operators](#_TOC000049)

[The equivalence of matrix without or with 0-dim. selection](#_TOC000108)

[5 Restrictions on arrays with selection](#_TOC000100)

[Inconvertibility to pointer](#_TOC000101)

[Restrictions for broken arrays before lvalue conversion](#_TOC000014)

[sizeof](#_TOC000043)

[& operator](#_TOC000045)

[typeof](#_TOC000040)

[Cast](#_TOC000046)

[\_Lengthof](#_TOC000046)

[Other Restrictions](#_TOC000103)

[Macros, selection forgetting and lvalue conversion](#_TOC000106)

[6 Assignments](#_TOC000052)

[Assigning an array](#_TOC000109)

[Assigning into an array](#_TOC000053)

[Overlapping in assignment](#_TOC000054)

[7 Other](#_TOC000110)

[The decaying of arrays to pointers](#_TOC000111)

[Literal 0 promoted to pointer](#_TOC000112)

[Mixing arrays with selection and arrays which decay to pointers](#_TOC000051)

[A[B:L][B’:L’] when the elements of A[B:L] are pointers](#_TOC000113)

[On modifiable lvalues](#_TOC000055)

[Miscellanea](#_TOC000056)

[8 Graded complexity of range selections](#_TOC000025)

[What would be mandatory](#_TOC000144)

[9 Indexed and direct selections](#_TOC000092)

[An array with selection as the index](#_TOC000114)

[The kinds of matrices allowed as indices](#_TOC000115)

[An array without selection, sometimes](#_TOC000116)

[An array without selection, always](#_TOC000153)

[The type of the selection](#_TOC000085)

[Singleton or not](#_TOC000154)

[Margins (again)](#_TOC000086)

[Relation to step zero selections](#_TOC000117)

[The most general selection carried](#_TOC000118)

[Direct selection](#_TOC000119)

[Constant range expressions](#_TOC000120)

[Constant or not](#_TOC000121)

[Comma separated list](#_TOC000122)

[10 Further extensions](#_TOC000079)

[A[B:-L]](#_TOC000080)

[Range selection constraint related recommended practice](#_TOC000082)

[Relaxing the UB of overlapping in assignments](#_TOC000083)

[Relaxing the restriction for overlapping](#_TOC000084)

[A[B:L][B’:L’] when the elements of A[B:L] are pointers](#_TOC000081)

[typeof, sizeof, \_Unselect() and \_Value()](#_TOC000090)

[Functions taking and returning arrays](#_TOC000157)

[11 Further editorial fixes](#_TOC000158)

[6.5.16 Conditional operator](#_TOC000159)

[6.5.17 Assignment operators](#_TOC000160)

[6.5.17 Assignment operators (again)](#_TOC000161)

[12 Wording](#_TOC000017)

[6.2.5 Types](#_TOC000162)

[6.5 Expressions](#_TOC000163)

[6.5.1 General](#_TOC000164)

[6.5.3 Postfix operators](#_TOC000165)

[6.5.3.1 General](#_TOC000166)

[Syntax](#_TOC000167)

[6.5.4 Unary operators](#_TOC000168)

[6.5.5 Cast operators](#_TOC000169)

[6.5.6 Multiplicative operators](#_TOC000170)

[6.5.7 Additive operators](#_TOC000171)

[6.5.8 Bitwise shift operators](#_TOC000172)

[6.5.9 Relational operators](#_TOC000173)

[6.5.10 Equality operators](#_TOC000174)

[6.5.11 Bitwise AND operator](#_TOC000175)

[6.5.12 Bitwise exclusive OR operator](#_TOC000176)

[6.5.13 Bitwise inclusive OR operator](#_TOC000177)

[6.5.16 Conditional operator](#_TOC000178)

[6.5.17 Assignment operators](#_TOC000179)

## Introduction

### Intent of the feature

The idea of the proposed extension is to be able to write code like

A[0:5] += 2;

A[:] = B[:]\*C[0][:];

A[:][0:6] += A[:][6:6];

A[*b*:*n*] = -B[0:*n*];

A[0:5:2] = 1/A[0:5:2]; // Operate on the elements 0, 2, 4, 6, 8

On the one hand, this makes code more synthetic and easier to read than **for** loops. On the other, it helps the compiler taking advantage of vector instructions present in the processor and, more generally, deciding which is the best way to transform that construction into machine code.

It also opens up the door for functions taking arrays as arguments. This is possible because we have chosen arrays with selected elements not to decay to pointers. This is explored in “Further extensions”.

### Prior art

The specification of a range in the index or a comma-separated list of values is common in many languages. Some languages specify begin and end instead of begin and length. In C, the former seems preferable, because the types of A[0:5] and A[n:5], where n is of integer type, should be the same, namely **typeof**(A[0])[5]. This is not possible if the latter is written A[n:n+5].

### Intent of the proposal

In a first step of the design we only defined continuous selections, and only one-dimensional. Stepped selections and multidimensional selections are a natural extension. This leads to a more complicated proposal. Not only the needed changes to the standard become longer, but the consideration of contrived examples grows considerably. Any design has to take into consideration any possible combination. These are thoroughly discussed here. In several cases the conclusion is that no extra wording is needed, but the study of the particular case is necessary nonetheless.

After these kinds of selections we considered the ones we call indexed selections and direct selections, which need yet further wording and consideration of cases. For these two we do not propose a concrete wording, though they are analysed to a point that brings them near wording.

Small implementations are reluctant to adopt complex features, and there is already a not so short list of optional features: variable length arrays, complex numbers, decimal floating numbers, atomics, threads, to which may be added recent additions to the language that some implementations do not plan to support in the foreseeable future. Some prefer to keep the language small and avoid any complex features, whether made optional or not. But at the same time implementations cannot be stopped (and should not be) from providing extensions, and it is good for the programming community if the way these extension are provided is standardised. For this reason we believe that the full set of features with respect to empty selection and range selections should be put in a standard form. Other features analysed in this paper go too far afield. We also believe that implementations should not be forced to implement the most complex combinations, or range selections at all.

We don’t intend the wording proposed here to be voted for inclusion in the standard now. Implementation experience is obviously needed. But implementations are reluctant to include new features; once a feature is included it can never be removed (except for compilers targeting a very specific market). Another reason is that the way an extension is provided by the implementation may be different to the way it is finally adopted in the language. This makes implementations especially reluctant in regard to extensions that are likely to be incorporated to the standard.

Therefore, an actual wording is desirable. The committee should express its intent in adopting the feature in some concrete from, the one proposed here or another one, but a concrete one, so that implementations can embark in the task of implementing it with the assurance that they are implementing the design that will be adopted by the standard. In doing this they may detect issues with the proposed wording that need adjustment, and the wording eventually comes to a final form. This way implementers see that they guide the shaping of the final wording, not that the final wording makes their implementation incompatible with the standard.

Another reason for developing the feature in full is that the analysis of more complicated cases helps in the design of the simpler ones. A gradual specification of the feature, where a first proposal just addresses the simplest cases ignoring any possible extension, may lead to wrong decisions in the design, that reveal themselves wrong only when the feature is extended and that it is by then too late to change.

This document, therefore, may serve as a basis for a technical specification or simply for a proposal available from the project page, to which the committee has expressed its approval but the wording of which may not yet be in final form and bears no normative power.

Once implementations begin implementing this, as we hope, the adoption into the wording of the standard may be done progressively, incorporating first single-dimensional, continuous (i.e., no step) selections, for example. Since the feature is likely to remain optional it may go into an annex (except empty selections).

Another feature that can be incorporated easily is the empty selection: A[], which essentially serves to suppress conversion to pointer of the matrix. We don’t intend this to be optional. The adoption of empty selections make very easy the introduction of functions that can take arrays as arguments, which may be the next addition in this line.

### Relation to other proposals

Range operations on arrays lead naturally to an empty selection for selecting the matrix as a whole and to matrices not decaying to pointers. The syntax that arises naturally for this should be taken into consideration by others thinking of a way of avoiding arrays decaying to pointer in some contexts; for instance, for functions taking arrays.

The proposal of fixing the order of evaluation in operations like A+B has to consider very carefully its implications for range operations, where the obvious translation consists in first evaluating all the expressions needed for determining all the ranges that appear in the expression (e.g., in an assignment expression), in our notation, B,L,s, then translate the range operation as a sequence of individual operations, as though it were a **for** loop.

We provide wording for the **\_Lenghtof** operator, for the case when the operand is an array with selection, as though the operator had already been incorporated to the standard. This operator will in all likelihood be adopted, with one or other name, before anything in this document. We also make use of it in some examples.

The terminology with respect to the number of elements and size of an array has to be very precise. We use the following terms: *length* to mean the number of elements. *Total length* is the product of the length of the array times the length of its elements and so forth; that is, the total length of an array is its length if its elements are not of array type, the product of its length times the total length of its elements otherwise. *Variable length array,* with its usual meaning, even though the term corresponding to that meaning should be variable size array. Its opposite is array of *known constant size*. Since there do not exist singletons (the term singleton is introduced soon in the proposal) of variable size, known constant size coincides with *known constant total length.* This latter term is used only once, at a point where it is important to emphasize that the text refers to the total number of elements, not the size. The opposite of this term should be variable length array, had not this term the meaning it has. If the length of the array is known (i.e., given by an integer constant expression), it is an array of *known constant length*; otherwise it is a *top-level variable length array.* We also use the term *fixed length* as a synonym of known constant length, but not in the wording.

## Selections [B:L], [B:L:s], [:] and [::]

### Semantics of range selection

Consider the code

A[0:5] += 2;

A[:] = B[:]\*C[0][:];

A[:][0:6] += A[:][6:6];

If A is an array A[B:L] denotes, or *selects*, the subarray of L elements A[B] ... A[B + L-1] and A[:] selects the whole array. Each of the selected elements is operated. In the second example A, B and C[0] have the same number of elements. In the third, for each A[*i*], to the first six elements the next six are added: A[*i*][*j*]+=A[i][*j*+6], for all *i* and for 0≤*j*≤5.

In expressions where one of the operands is not an array with selection, that operand should be evaluated only once. Thus, in

**int** i=2;

A[0:5] = i++;

All five elements in A[0:5] are assigned the value~2 and after the expression is evaluated i equals 3.

The semantics for arrays with selections in just one dimension is for the most part easy with a unique obvious choice. Multidimensional selections, however, give rise to many situations which need careful decisions and wording. One of this is the combination of selections with the array subscripting operator, [*k*].

### Singleton

Before anything else, we introduce the concept of singleton. For a time it appeared that we could get along with the expression “element of non-array type”, but in the end it proved impossible in practice. As way of example, this document contains well over one hundred uses of the term. The definition we provide for it is as follows:

*An object or value which is not of array type is called a* singleton. *If the element type of an array is not an array type, the elements of the array are* its singletons. *If the element type is an array type, the singletons of the array are those of its elements.*

Note that this excludes the type **void**.

### Continuous subarray selection

If A is an array we’d like A[B:L] to denote the subarray of L elements A[B] ... A[B + L-1]. It seems this should be an array of L elements; that is, it should have that type. Also, A[:] should denote the whole array, i. e., the same object as A.

This poses a problem for multidimensional arrays: we’d like, e. g., A[0:4][0:3] to denote a bidimensional array, or rather a selection thereof, not the first three elements within A[0:4]. But if A[0:4] is to be an array just like A, differing only possibly in the number of elements, how can that be achieved? It is necessary that A[0:4], in addition to its type, carries some property with it that can distinguish it from an array of four elements of the same type. We will say that A[B:L] or A[:] have elements selected, or that they are arrays with selection, or that they carry a selection, which a “plain” array does not.

Thus, after a declaration of the type

**int** A[10];

A[0:3] has type “array of three int”. In addition, it has its three elements selected, which the expression A does not.

This makes possible to select the next dimension if there is one:

**int** A[4][5];

**int** B[10][5];

A[0:3];

B[0:4][0:3];

Here both A and B[0:4] have type “array of four array of five int”, but A does not carry a selection of elements while B[0:4] does. For this reason

A[0:3]

denotes an array of three elements of type “array of five int”, which makes 15 elements, while

B[0:4][0:5]

denotes an array of four elements, also of type “array of five int”. The former has its three elements selected, which are of type “array of five int” while the latter has twelve elements selected in a 4 x 3 array, which have type “int”.

The rule is that, in an expression of the form

A[B:L] or A[:],

if A does not carry a selection the operand selects elements from the first (outermost) dimension of A, of type that of A[0], while if it does already have selected elements it selects elements from each of the already selected elements: in the expression A[B:L], for each s selected in A, the elements s[B:L] are selected.

So, if A is an array of *n* dimensions, its selection, if any, will have the form of an *l*-dimensional array of *m*-dimensional arrays, and *l*+*m* = *n*.

We do not allow further selections applied to an array carrying a selection whose elements are pointers. See “Further extension” for a discussion.

### The type after lvalue conversion

When working with arrays with selections it is soon realised that what matters for an operation between two of them to be possible is just the number elements selected from each dimension, not which particular elements are selected not even how many elements the full array has. For example:

**int** A[24][8][3], B[6][8][10];

A[0:6:2][0:4][:] + B[:][2:4][7:3];

But then we can completely discard the non-selected elements and make the type of the arrays with selections in this example be **int**[6][4][3]. There is no concern here about the memory layout of the array after lvalue conversion, since the result of such a conversion is just a value, not an object.

This is not possible for l-values:

**int** A[18][8][3], B[6][8][10];

A[0:6:2][0:4][:] = B[:][2:4][7:3];

Here it is precisely the elements A[0:0:0], ... A[10][3][2] which need have their values updated.

### Broken arryas. Long and short interpretations

We said above that A[:] or A[B:L] are arrays like A, differing possibly in the second case in the number of elements. Let us consider the case A[B:L] when A is itself of the form C[:] or C[B:L], as in the following example:

**int** A[10][5];

A[2:4][0:3];

The layout of A[2:4][0:3] is as follows, where s denotes an element that has been selected and will be operated and *i* an element which will be ignored:

s, s, s, *i*, *i*, s, s, s, *i*, *i*, s, s, s, *i*, *i*, s, s, s, *i*, *i*

The twelve elements which constitute the selection, the ones which will be operated (e.g. as A[2:4][0:3]\*=2), are not stored consecutively. We will call one such selection, which is like an array with padding, a *broken array*; and each dimension with a selection in which not all the elements are selected, we will call a *broken dimension*. We may assign to A[2:4][0:3] type **int**[4][3], or **int**[4][5]. Both options have advantages and drawbacks. The former choice will be called the *short interpretation*, while the latter will be called the *long interpretation*. There is also the possibility of assigning it a new type.

#### New type

These broken arrays made us think for a moment to enlarge the type system for them, based on the principle that one of the characteristics of a type is the layout of its elements. Thus, each broken array would be akin to a structure, broken arrays differing in the number of elements in each dimension or the selected elements from each of these being of different type. For example, A[:][0:2] and A[:][2:2] would be of different types. Apart from the enlargement of the type system, that we prefer to avoid, this choice presents another problem: what would be the type of A[:][0:2] + A[:][2:2] ? This latter is readily solved by the way we specify lvalue conversions of arrays with selections. We still prefer not to enlarge the type system for arrays with selections.

#### Long interpretation

We cannot naïvely assign A[2:4][0:3] above type **int**[4][3], since the memory layout of the object is not that of an **int**[4][3]. It is that of an **int**[10][5], with some elements selected, others ignored. With this interpretation, each broken array has a corresponding *full array,* which is the array from which it is a selection, with no selection.

This choice poses a dilemma when the range [B:L] is selected from the outermost dimension of a declared array A. For symmetry with inner dimensions we would say that A[B:L] is a broken array, but this contradicts what said at the onset of the *Continuous subarray selection* section about the type we want for A[B:L] and leads to some unexpected semantics, as in

**int** A[10];

**sizeof** A[0:1]; //Would equal 10\*sizeof(int)

Furthermore, the selection [B:L] may be applied to a pointer, in which case the result must necessarily be an array of L elements.

For these reasons we prefer to let the type of A[B:L], when A is an array which does not carry a selection, be that of the sliced down array; i.e., the same as that of A except possibly for the number of elements:

**int** A[10][5];

A[2:4]; //Same type as **int**[4][5]. All its four elements A[*i*] are selected.

A[2:4][0:3]; //The type is **int**[4][5]. The selection is a broken array.

A[2:4][:]; //The type is **int**[4][5]. All its 20 elements A[*i*][*j*] are selected.

All three objects in the example have the same size; namely, that of an **int**[4][5].

The main drawback of the long interpretation is that the type of a broken array changes upon lvalue conversion. Thus, A[2:4][0:3] is an **int**[4][5] before lvalue conversion and an **int**[4][3] after it. This makes the use of broken arrays dangerous as operands to **sizeof**, **typeof** and other places.

#### Short interpretation

As already pointed, we cannot just say that the type of A[2:4][0:3] is **int**[4][3]. Yet, that would make the type of that array the same before and after lvalue conversion. The solution is to attatch to it a qualifier. Thus, A[2:4][0:3] is not a “plain” **int**[4][3] but a *broken* **int**[4][3]. Brokenness is a qualification the array carries, as could be its being atomic. The register storage class achieves a similar effect: the memory layout may be different from that of an object without that storage class. Contraty to a type declared with a qualifier, the type of the object is the same. We will discuss at the end of the analysis, just before the wording, whether we want broken arrays in the short interpretation to be atomic-like (qualifier) or register-like (storage class).

The type of the arrays considered above is now

**int** A[10][5];

A[2:4]; //Same type as **int**[4][5]

A[2:4][0:3]; //The type is **int**[4][broken 3]

A[2:4][:]; //The type is **int**[4][5]

The word brokenis not a keyword proposed, just a symbolic way of representing the type of broken arrays in the short interpretation.

Here there is no dobut that the type of A[B:L] is **int**[L]. It is not broken because it is not broken in the literal sense; i.e., its elements are not spread out.

In the short interpretation, whenever a dimension carries a selection, all the elements of the array which carries the selection are selected; the elements of the original array that were not selected do not form part of the array after selection.

#### The choice taken

In the end we chose the short interpretation. All this document considers both the long and short interpretations. This is for one reason: in order to assess the two options the implications for the different operands have to be analysed in detail. The long interpretation presents more nuances than the short one, which is more straightforward. It presents, for instance, the dichotomy of margins or not margins (to be explained later), the interpretation of array subscripting, etc. After pondering the drawbackd of both interpretations, we choose the short one. The proposed wording, accordingly, is for the short interpretation.

#### The type of A[B:L] for nonconstant L

#### A variable length array

If L is not a constant expression a fixed length array could be turned into a variable length array, and vice-versa:

**int** n = 4;

**int** A[10], B[n];

A[0:n]; //Variable length array

B[1:2]; //Array of known constant size

We should consider with respect to this problem what should be the semantics when A is a pointer, not an array, as in

**void** mult\_array(**float** \*A, **float** \*B, **float** \*C, **int** n){

A[0:n] = B[0:n] \* C[0:n];

}

It seems difficult to make A[0:n] have a type other than variable length array of length n.

All this leads us to let the type of A[B:L] when A does not carry a selection be **typeof**(A[0])[L].

When A does carry a selection, the type is be given by the length of A in the long interpretation; i.e., it is the same as that of A, while in the short interpretation it is always **typeof**(A[0])[L], and may or may not be broken.

#### Mandatory VLA

Consider

A[0:n] /= 2;

It seems that an implementation should support this even if it does not support variable length arrays. A closer thinking reveals that the equivalent to A[0:n] is not an object declared as a variable length array but a **for** loop. The translator need not handle any memory allocation.

C23 does not require support for VLA of automatic storage duration. We also have from the standard that *An lvalue is an expression (with an object type other than* ***void****) that potentially designates an object;* So, A[0:n] is an lvalue and designates an object which may have (and will typically have) automatic storage duration and is a VLA. We want support for these mandatory.

The wording for making these mandatory should be in the text explaining the meaning of the **\_\_STDC\_NO\_VLA\_\_** macro, which states what is not mandatory. Then, the wording for the latter can take an include approach or an exclude approach. On the one hand, it may state precisely which VLAs are not mandatory. These would be henceforth the objects with automatic storage duration *declared* as VLA. On the other it may rule out which ones are not mandatory.

First approach:

**\_\_STDC\_NO\_VLA\_\_** The integer constant 1, intended to indicate that the implementation does not support the declaration of variable length arrays with automatic storage duration.

Second approach:

**\_\_STDC\_NO\_VLA\_\_** The integer constant 1, intended to indicate that the implementation does not support variable length arrays with automatic storage duration which are not part of an object of known constant size.

The second approach is more conceptual, focusing on the reason why those which arise from a range selection should be mandatory, not mentioning specifically range selections. If there were other instances in the language of those, they should be mandatory. But given that there are no other instances, the first wording makes it easier for a reader to know exactly what support for VLA is not mandatory. Therefore, we took the first approach.

### The selection [::]

Consider the following code:

**int** A[3][3], B[3][3], C[3][3];

A[:][:] = B[:][:]+C[:][:];

It may seem more natural to write

A[:] = B[:]+C[:];

A “partial selection”, in which there are not as many [:] or [B:L] as possible seems of very limited use. For this reason it was considered to make a [:] selection operate on all the dimensions, except that if selections [B:L] follow, these refer to the innermost dimensions and the [:] would apply to the remaining ones. There should not be more than one [:] in a series of consecutive selection operators.

However, others may prefer not to have a special rule for [:]. Furthermore, for the operators == and != these partial selections are useful.

Both sensibilities can be reconciled by devising a different syntax for the selection of the whole matrix. We chose [::] for it:

A[::] = B[::]+C[::];

For a time we relegated this to “future extensions”, but it proved so useful when working with multidimensional arrays that we included it in the main proposal. We found ourselves using it in, e.g.,

C[::] = (A[::] == B[::]);

This has the advantage that the programmer need not care about the number of dimensions of the matrices involved. The above statement is written the same way whether A, B and C are unidimensional, bidimensional, etc. Of course, the dimensions of the three matrices must match. This can be very useful for macros.

Also, it expresses intent better than

C[:] = (A[:] == B[:]);

Here, the reader of this code cannot know just by looking at it if the comparison is carried at the level of the singletons or if the matrices are multidimensional and the comparison is between vectors or matrices (see below the discussion for the == operator).

As noted above, we make [::] select all dimensions up to the following [], [:], [B:L] or [B:L:s] selections if present (see the wording).

### Stepped selections

We want also to allow “stepped” selections: A[0:5:2], which selects the elements A[0], A[2], A[4], A[6], A[8]. Or A[0:n:2], which would select A[0], ... A[2(n-1)]. The third integer in the selection is the *step,* which can positive, negative, or zero with some restrictions, and need not be an integer constant expression.

All we have discussed applies to stepped selections, with one exception; in particular, lvalue conversion transforms a stepped selection into a continuous array. The exception is a stepped selection as the first, outermost one. This creates from the outset an array with its first dimension broken.

Long interpretation

If A is an array which does not carry a selection, s is an ICE and either s is zero or L is an ICE (or both)

A[B:L:s] has type int[s\*(L-1)+1] (for s≥0).

The choice s\*L is also natural, each selected element being followed by s-1 padding elements. But this is not possible for cases like **int** A[7]; A[0:3:3], where the last selected element is also the last element in the array. Nor is it possible if s is zero. If s is negative, it is its absolute value which is taken.

Both interpretations

Needless to say, if s is negative it is the highest element which is operated first:

A[2:3:-1]= B[0:3]; // A[2]=B[0], A[1]=B[1], A[0]=B[2]

A[8:3:-3] lvalue conv.

 {A[8],A[5],A[2]}

### s equal to zero

s might evaluate to zero. If the array with selection undergoes lvalue conversion, L copies of the element A[B] will fill the array. In the long interpretation, an array of one element results if [B:L:0] is the outermost selection. In the short interpretation the resulting array always has L elements, even if they will share the same location in memory.

Finally, s cannot be zero if the array is the left operand of an assignment:

A[n:10:0]+=1; // Not allowed

In the proposed wording, instead of saying “if s evaluates to zero the array shall not be the left operand of an assignment operator” we write “an array which carries a stepped selection where the step is zero shall not be the left operand of an assignment operator”. This is to make unambiguous that the following is valid:

A[6:10:0][2]= 2.0; // Equivalent to A[6]= 2.0.

It also makes valid, according to the precise definition of *stepped selection* that will be given, an s equal to zero provided L is one:

A[6:1:0]= 2.0; // Valid. Equivalent to A[6]= 2.0.

Long interpretation

If the element type of A is **int** (or A is a pointer to **int**), A[B:L:0]has type **int**[1] with no ignored elements. It is not a broken array.

A corner case arises if A[B:L:s] is an array of known constant size, s is an ICE which evaluates to zero, L is not an ICE and A[B:L:s] undergoes lvalue conversion. Before lvalue conversion the array has size 1 and is therefore of known constant size. After the conversion it has L elements, hence is not of known constant size. This is the only case where lvalue conversion changes an array of known constant size into a VLA. We think this is not problematic since the translator will handle the array after conversion in either of two ways:

* It copies the selected values in a temporary object in memory, the amount of copies is not known at translation time. This happens already (in this proposal) for any array with selection which is not of known constant size.
* The elements are operated with some other element or the elements of another array with selection; these operations are translated as a **for** loop. Then, the fact that s is zero is irrelevant: each iteration of the **for** loop reads the required value, be it always the same or not. We *do not* allow constructions where the repeated element would be the destination of writing operations.

It would be problematic for unary operators, as in A[0:L:0]++. But here the problem arises independent of L not being a constant expression. It is the one just treated above, which is solved by not allowing stepped selections where s is zero as the left operand of an assignment operator.

lvalue conversion of an array with a stepped selection where *s* is zero and *l* is not one constitutes an exception, in that the array after lvalue conversion has more elements than before; in any other situation is has the same or less elements.

Short interpretation

Now the type of A[B:L:0] is **int**[*l*], even before lvalue conversion. If *l* is ≠1, its layout is very different from a plain **int**[*l*]; its *l* elements share the same space in memory. For this reason its type has to be qualified somehow. We could say that it is collapsed, but we prefer to reuse the broken qualifier for this. Thus, *boken* does not necessarily mean spread out, but *having a layout different from the unqualified array;* typicaly because its elements are spread out, but can also be the opposite: different elements sharing the same space in memory.

### The kind of expressions allowed for B, L and s

We believe it should not be more than *conditional-expression*. As regards side effects, our opinion alternated between prohibiting them and allowing them. Side effects would complicate the translation and be a source of bugs, as in A[n:n++]=0 or A[0:b[0]=3] + b[0:3]. On the other side, these constructions have parallels in what can currently be done:

n= n++; (b[0]=3) + b[0]

As for the complication in the translation, the translator must evaluate B, L and s before translating the range operation proper, so side effects take place naturally at that point. Finally, there are use cases that seem natural, as

A[0:n++]= x; A[k:3] = B[f(k):3];

So in the end we allow them.

Conditional expressions cause no ambiguity in the interpretation of :. Parentheses can ease readability: A[(b ? 0:n) : n].

## Broken arrays

### Array subscripting applied to an array with selection

Consider the following:

**int** A[9][6];

A[5:4][0];

A[5:4][1:2][0];

The following appealing interpretation, in which the [*k*] operand applies to each of the selected elements:

A[5:4][0]; // {A[5][0], *i*, *i*, *i*, A[6][0], *i*, ... A[8][0]}

A[5:4][1:2][0]; //Wrong, there are not three dimensions

is at odds with the definition of the [*k*] operation as selecting the *k*-th element of the object to its left. A[5:4][0] should be A[5]. This means that for the [*k*] operator the array of selected objects should not be treated as a range of objects (to be explained below). The semantics of the above examples should be:

A[5:4]; // {A[5][0], ... A[5][5], A[6][0], ... A[8][5]}

A[5:4][0]; // A[5] = {A[5][0], A[5][1], ... A[5][5]}

A[5:4][1:2][0] // {*i*, A[5][1], A[5][2], *i*, *i*, *i*}

If the user wants to select the 0-th element from each selected array, he should write

A[5:4][0:1];

In the last example A[5:4][1:2][0] is a unidimensional array, yet that dimension is broken in the long interpretation. This cannot happen as a result of selecting elements from an array with [B:L] or [:] selections, the first dimension is never broken in those cases; nor is it in the short interpretation, where A[5:4][1:2] has type **int**[4][2], hence A[5:4][1:2][0] has type **int**[2]. We consider below in the section “Margins” another possibility for A[5:4][1:2][0] in the long interpretation.

### Array subscripting when the first dimension is broken

Long interpretation

Consider the following examples:

**int** A[9][6];

A[0:3:2][1]; // A[1] or A[2]?

A[5][1:2]; // Array of type **int**[2]: {A[5][1], A[5][2]}

A[5:4][1:2][0]; // {*i*, A[5][1], A[5][2], *i*, *i*, *i*}

A[5:4][1:2][0][1]; // A[5][1] or A[5][2]?

A[5:4][1:2][0][0]; // Wrong, it would be A[5][0], which is amongst the ignored elements? Or A[5][1]?

We said that A[5:4][1:2][0] has type **int**[6]. So, a further [0] should refer to its first element. Alternatively, we may posit that the array subscripting applied to an array with a selection operates on the selected elements. That would break the equivalence between [0] and \*, unless the action of \* is also redefined. We do not consider the latter possible: the address of and object should be that of its first byte. On the other hand, the very way in which the selection [B:L] is defined points towards an index in [*k*] being counted from the first selected elements. Considering this, three options are possible:

Forbid the [*k*] operator on arrays where the first dimension is broken.

The index in [*k*] counts from B and steps s. \* selects the first element.

The index in [*k*] counts from B and steps s. \* is forbidden on arrays with selection.

We finally went for the third option. \* operates on pointers, while the purpose of a selection in an array is to denote the array itself (restricted to the selected elements), a range of elements on which an operand will operate; it cannot be a pointer.

Short interpretation

Now the situation is simpler because the broken array only carries with it the selected elements. We could even allow \*, but we prefer not to allow it, for the reason just expressed.

### Margins

All this section appertains only to the long interpretation, except when otherwise noted.

A broken outermost dimension can arise because of two reasons. One is a stepped selection, the other the combination of range selection and array subscripting:

**int** A[20][6], n;

A[5:4:3];

A[9:4:n];

A[5:4][1:2][0];

This latter only generates a broken outermost dimension in the long interpretation.

#### Mixing of range selection and subscripting

Consider this case first. A[5:4][1:2] is composed of four pieces:

{*i*, A[5][1], A[5][2], *i*, *i*, *i*} {*i*, A[6][1], A[6][2], *i*, *i*, *i*}

{*i*, A[7][1], A[7][2], *i*, *i*, *i*} {*i*, A[8][1], A[8][2], *i*, *i*, *i*}

so it seems the most natural that A[5:4][1:2][0] should be the first of these pieces. This results in unselected elements at the ends (margins).

These margins can be eliminated in the obvious way: letting A[5:4][1:2][0] be

{A[5][1], A[5][2]}

This goes against the most basic rules of arrays. First, an array should be the composition of its elements. Secondly, its number of elements should be **sizeof**(A[5:4][1:2])/**​sizeof**(A[5:4][1:2][0]). It has the advantage that the following two expressions are equivalent:

A[5:4][1:2][0] A[5][1:2]

Some drawbacks of this interpretation disappear if we think of the operation [0] not as selecting the 0-th element of the array with selection to its left, but as the selected elements therein. Thus, [*k*], when applied to an array carrying a selection, selects the selected elements from the array’s *k*-th element if these elements are of array type and carry a selection, or the *k*-th element if they are singletons or arrays which do not carry a selection. This way A[5:4][1:2] is still the juxtaposition of its four elements and each of them has a size of 5\***sizeof**(**int**).

With this interpretation we have **sizeof**(A[5:4][1:2][0]) = 2\***sizeof**(**int**) because [0] does not select the whole element. (But we are not allowing **sizeof** on arrays which carry a broken selection).

Another advantage of this interpretation is that **typeof**(A[5:4][1:2][0]) is **int**[2], which is the more natural choice given that A[5:4][1:2][0] has only two elements that can be addressed with no holes in-between; namely, [0] and [1] (But we are not allowing **typeof** here either).

It has the drawback that [*k*] does not select the array’s *k*-th element. We may think of

A[R][R’]...[*k*][*k*’]...

where [R], [R’], ... are range selections, of which only the first one need be present, *b* is the first element in the selection R and [*k*]*,* [*k*’]*,* ... are array subscriptings of which only the first one need be present, as a longhand for

A[*b*+*k*][R’]...[*k*’]...,

except that if [R] is [::] it is first replaced by the equivalent number of [:] selections. But this still leaves one uneasy.

#### Stepped selections

In this case there will be holes between the selected elements, if the step is >1 or <-1, but there will not be empty margins. For example, the layout of A[5:4:3] is

{s, *i*, *i*, s, *i*, *i*, s, *i*, *i*, s},

where *i* stands for “ignored” and s for “selected”.

Long interpretation

The layout of A[10:4:s] if *s*≠0 is

{s, *i*.(*s*-1), s, *i*.(*s*-1), s, *i*.(*s*-1), s}

where *i*.(*s*-1) means *s*-1 ignored elements (If *s*=0 the layout is {s}). But, which s among these four is A[10]? The first one or the last one? In the long interpretation it depends on whether *s* is positive or negative.

This seemed at first problematic. An object should have a well-defined address and proceed forward in memory. A variable length array can lead to a similar situation, as in

**int** A[3][n];

where the address of A[1] is (**int**\*)A+n. But in this case the translator knows that the object A[1] starts behind of A and that its first element is A[1][0].

This made us consider the following design for the long interpretation: In a stepped selection where the step is not an ICE the expression (the stepped selection) consists of all the elements of the array. For example, in the selection A[10:4:s], with s not an ICE and supposing it evaluates to -3 when evaluated, the layout would be:

{*i*, s, *i*, *i*, s, *i*, *i*, s, *i*, *i*, s, *i*, *i*, *i*, *i*, *i*, *i*, *i*, *i*, *i*, *i*}

This way the translator always knows the size and address of the array with stepped selection.

Another consequence of this design is that if A has pointer type and *s* is negative it has to be given by an ICE. Or as it would be written: If A has pointer type and s is not an integer constant expression *s* shall not be negative. So that in A[B:L:s] the translator can know that the selection will span the positions

*from* B *to* B + (L-1)\*s

We can form the expression B + (s<0)\*(L-1)\*s that gives unconditionally the lowest address element of the selection, but the compiler cannot know whether this lies ahead of A+B or behind, contrary to VLA, where it always knows it lies behind.

But since B itself may not be an ICE it turns out that stepped selections with a negative step are no more complicated than selections without step can be, as regards the size and the position of the lowest address selected element:

A[B:L:s]

A[B’:L’] *as in* A[ B+(s<0)\*(L-1)\*s : 1+(L-1)\*abs(s) ]

Since in the second case we let A[B’:L’] span only the selection, from B’ to B’ + L’-1, there is not reason in A[B:L:s] not to do the same. Indeed, it seems we should do the same.

Therefore, a selection A[B:L:s] will always be as follows: It span from A + *b* + (*s*<0)\*(*l*-1)\**s* to A + *b* + (*s*<0)\*(*l*-1)\**s* + (*l*-1)\*|*s*| = A + *b* + (*s*>0)\*(*l*-1)\**s*. And there is no restriction on s when A is of pointer type.

Short interpretation

The layout of A[10:4:s] can be represented as {s, ? , s, ? , s, ?, s} and A[10] is always the first s. In a selection A[B:L:s], its first element is the one at A + *b*; its last element, the one at A + *b* + (*l*-1)\**s*, whether *s* be possitive or negative.

Both interpretations

All the above applies before lvalue conversion. After lvalue conversion ithe array has the *l* elements in order, and there is nothing to say about its memory layout, for it is, conceptually, just a value.

#### Both constructions

(This contiues to apply only to the long interpretation)

In order to assess the different options (margins or not margins) we have to ask ourselves when does the difference matter. If the expression is undergoing lvalue conversion the distinction is irrelevant. If it is the left operand of an assignment, the type given to it is also irrelevant (and the expression itself undergoes lvalue conversion). It turns out that the contexts where it matters have been excluded in this proposal: **sizeof**, **typeof**, taking its address, decaying to pointer. Another situation, what element is selected by the [*k*] array subscripting, has been settled by making the index count only selected elements, irrespective of brokenness: margins and holes.

Whatever the criterion chosen it has to be uniform. We envisage three possibilities with respect to A[R], where A is a pointer or an array not carrying a selection:

— Never trim margins. The type of A[R] is always that of A

— Trim margins if the selection is given by ICEs, keep them if there is even one not-ICE

— Always drop margins. A[R] spans from the first to the last of the selected elements

For B[*k*], where B carries a multidimensional selection, we see three possibilities, in partial correspondence with the previous ones:

— Never trim margins. The type of B[*k*] is the element type of B

— Trim margins if the selection is given by ICEs, keep them if there is even one not-ICE

— Always drop margins. B[*k*] spans from the first to the last of the selected elements

The option chosen for B[*k*] has to be ≤ the option chosen for A[R]. For example, if the second option is chosen for A[R] only the first or second options can be chosen for B[*k*].

Giving A[R] the same type as A when the latter is a pointer is strange. We finally chose the third option with respect to A, as explained above for stepped selections. While it may require run-time computations, the situations where they are needed would happen seldom, this is already the situation for VLA, and precisely in those contexts, and the optionality provided via the macros **\_\_STDC\_ARRSEL\_** allows an implementation not to handle those cases at all if it so wishes.

As for B[*k*], we finally chose that it be the whole *k*-th selected element of B, including margins if there are. This is the most coherent; margins will be dropped at lvalue conversion, together with all other unselected elements, and it does not affect the meaning of a subsequent [*k*], which will always be the *k*-th selected element in B[0].

We have therefore made up a decision for the long interpretation. For the short interpretation, which we finally take, the situation is much simpler.

### Pointer to one of its elements; valid offsets

We forbid taking the address of an array with (nonempty) selection. But the address of one of its elements may be taken and the user can make use of that pointer to access elements from the array:

**int** A[10], B[6][6];

**int** \*p= &A[0:4:3][0];

**int** \*q= &B[:][0:3][0][0];

As with any other pointer to an array element, these pointer can only be used to access elements from the array it was extracted from, not from any larger array of which the former array is a subarray:

p[0]=0, p[3]=1; // Valid

p[1]=2; p[0]=p[4]; // Invalid (U.B.)

q[2]=q[1]=q[0]=4; // Valid

q[4]=0; // Invalid

This allow the compiler to reason about elements not modified by the pointer:

**int** A[6][3], B[6][6];

**int** \*q= &B[:][0:3][0][0];

// Operations using q

A[:][:] = B[:][3:3];

In the code above the compiler can reason that no access through q modifies the upper three elements of each B[*i*], and advance the reading of those elements, needed for the last instruction (e.g., if the whole instruction is placed before).

A pointer taken from an array carring a step-zero selection will modify all the elements when modifying one of them. But this has not importance; those arrays are not allowed as the left operands of an asignment, and when undergoing lvalue conversion, the meaning for the translator is just “take element at *b*, *l* times”:

**int** A[6], B[6];

**int** \*q= &A[3:6:0]; // q is &A[3]

q[0]=5; // Modifies A[3]

q[1]=1; // Invalid

B[:] = A[3:6:0]; // Could have been written more clearly as B[:]=A[3].

The element of which the address is taken can itself be an array, but not an array with selection:

**int** A[6][6];

**int** (\*p)[6]= &A[0:4:3][0];

p= &A[:][:][0]; // Invalid: addresss of an array with selection

## Relational operators and empty selections

### Equality operators

What should A[:] == B[:] yield? From the point of view of the == operator it should evaluate to true if all elements are equal. From the point of view of a range operation it should yield an array of 0’s and 1’s. It will eventually become unavoidable to provide syntax for the two options. If either or the other choice is taken for the equality operator, it seems that another operator would be necessary for the other.

Let us analyse the range operator point of view:

**int** A[3][3], B[3][3], C[3][3], D[3], E;

C[:][:] = (A[:][:] == B[:][:]);

D[:] = (A[:] == B[:]);

E = A *op* B;

Making == operate as any other operator on the range of selected values lets the programmer choose at what level the comparison is carried: At each singleton level, resulting, in the example, in a 3×3 matrix; at the level of the next to last dimension, comparing vectors, the result being true if all components are equal, yielding the value assigned to D in the example, which is equivalent to

D[0] = A[0][0]==B[0][0] && A[0][1]==B[0][1] && A[0][2]==B[0][2];

D[1] = A[1][0]==B[1][0] && A[1][1]==B[1][1] && A[1][2]==B[1][2];

D[2] = A[2][0]==B[2][0] && A[2][1]==B[2][1] && A[2][2]==B[2][2];

And there is one obvious possibility missing: comparing all the elements yielding a single value, assigned to E in the example. There is no need for a new operator, just syntax for selecting a 0-dimensional selection.

Therefore, the right choice is to treat == and != as any other binary operator and operate on the selected elements. There is no need for the duplication of all comparison operators.

We define A != B to be !(A == B). Here, the result of A == B is a matrix with all its elements selected, and ! negates each of them. For example, with A and B as above,

A[:] != B[:] is equivalent to !(A[:] == B[:])

A[:] == B[:] yields an array of three elements with all its elements selected, and the ! operator negates each of them. That is, the result is equivalent to

[0] = !( A[0][0]==B[0][0] && A[0][1]==B[0][1] && A[0][2]==B[0][2] )

[1] = !( A[1][0]==B[1][0] && A[1][1]==B[1][1] && A[1][2]==B[1][2] )

[2] = !( A[2][0]==B[2][0] && A[2][1]==B[2][1] && A[2][2]==B[2][2] )

### 0-dimensional selection

After the declaration **int** A[3][3] we have the following possibilities with respect to the dimension of the selection and that of the selected elements, to which we add now the last entry:

| Selection | Dim. of selection | Dim. of selected elems. |
| --- | --- | --- |
| A[:][:] | 2 | 0 |
| A[:] | 1 | 1 |
| A[] | 0 | 2 |

The last option selects the matrix as a whole. It has one selected element, which is a 3×3 matrix. This is the formal explanation. In practice for the programmer it means that the matrix is treated as a whole, for instance for the == and != operators, and that it does not decay to a pointer, the latter formally because it carries a selection.

Once we have settled onto providing some way to perform a 0-dim. selection, a syntax has to be chosen for it. We considered two options:

[A] A[]

None of them presents incompatibilities or ambiguities with the current uses of the [] operator. The first one, since for its use as array subscripting an expression must precede it, while in the construction [A] here, an expression cannot precede it. For the second one, an empty [] is only allowed in declarators, and even there only in some places.

The second one is in keeping with the syntax of the other range selections. On the other hand, the semantics of a zero dimensional selection is essentially to avoid the matrix decaying to a pointer. It has no effect when applied to a matrix that already carries a selection:

A[0:5][][:] is equivalent to A[0:5][:]

And it wouldn’t be needed for the == operator if its operands did not decay to pointers. With this view, the syntax [A] conveys the idea that the brackets *protect* the matrix; then we could say that a *protected* matrix is never converted to a pointer. It also becomes clearer that this *matrix-protection* operator has no effect on an array with selection, which cannot already decay to a pointer:

[A[0:5]] is equivalent to A[0:5]

If the protection of a matrix is part of the replacement text of a macro, this may lead to the occurrence of two consecutive [ tokens: [[A]], which has the syntax of an attribute. This can be solved by defining the macro as

**#define** protect(a) [(a)]

The other obvious choice, [ a ], is not possible because of the decision of C of interpreting [[ not as one token but us the succession of two tokens. C++ already has a similar problem with the << operator, whereby nested templates need a dividing space between two consecutive <.

A more important reason strikes a death blow on this syntax: An array within brackets may be needed, and will very likely be in some implementation providing the extension, for specifying an arbitrary sequence of indices to be selected:

**unsigned int** I[3] = {0,4,3};

**float** B[3], A[10];

B[:] += A[I];

Strictly speaking, this does not rule out the [A] syntax for a zero selection, since in one case the operator must be preceded by an expression of array or pointer type and in the other case it cannot, but using the same syntax for two different operations with the same possible type for the operand is a very bad choice if it can be avoided.

Therefore, without any doubt the A[] syntax should be preferred over the [A] one.

### Relational operators

The relational operators are <, >, <= and >=. When a relational operator is applied to an array with selection we mandate that the selected elements be singletons. This excludes the analogous of A[:] == B[:] or A[] == B[] in the examples above. While it is clear that two vectors or matrices should compare equal only if all elements compare equal, it is by no means clear that A should be < B if all elements of A are less than all corresponding elements of B. Furthermore, this would make < and > not the opposite of >= and <= respectively.

That semantics can be achieved with the current proposal, though an intermediate variable is needed:

C[:][:] = (A[:][:] < B[:][:]);

(C[] == 1)

### The equivalence of matrix without or with 0-dim. selection

We saw that an empty [] selection is sometimes needed for preventing the matrix to decay to a pointer (we recall, we called this to *protect* the matrix). Both:

E[] = D[]; and E = D[];

are possible and have the same meaning, but

E[] = D; and E = D;

are not, because D decays to a pointer.

For passing the matrix as argument to a function, in the event that function arguments are extended to allow arrays, the 0-selection is the most natural syntax;

**double** determinant3(**double** A[:3][3]);

determinant3(Α[]); determinant3(A[:]);

determinant3(A[:][:]); determinant3(A[::]);

All four calls are equivalent since the selection is lost (in our design) when the matrix is passed as argument to function, but it seems to us that the first one is the more natural one.

It is also the most natural option when we want the type of a matrix to be that of a declared identifier:

**auto** a = Α[];  **auto** a = Α[:]; **auto** a = Α[::];

Again, all three forms are equivalent, but it seems that the first one conveys meaning better, since the selection is irrelevant.

In the three examples the [] operator has no other function than to protect the matrix, and this is also the case when used for the operands of the == and != operators, though here there is a parallel with matrices carrying “smaller” selections.

We’d like that to be the general case; that is, there should be no semantic difference between a matrix which does not decay to a pointer and a matrix with a zero selection. If we want to preserve this in the current proposal we may need to allow matrices with 0-dimensional selection in places where we will preclude matrices with selection. This will be treated in the next section. It turns out there is only one such situation:

&A[]

(arbitrary arrays with selections will be excluded from other places, but arrays containing very simple selections will not). Arrays with selection will be precluded from these places because a different semantics may be wanted in the future for arrays with selected elements and specifically for broken arrays. There is no problem therefore in allowing arrays with zero dimensional selections there. It should be noted that this does not make a selection like A[B:L][] allowed as operand for those operators, which would completely break our decision of not to allow arrays with selections there:

**int** A[5][5];

&Α[]; &Α[0][]; //Allowed

**&**Α[0:1][]; //Not allowed

This agrees with our specification that a [] selection applied to an array which already carries a selection has no effect.

## Restrictions on arrays with selection

### Inconvertibility to pointer

The section on array subscripting suggested that an array with a selection should not be convertible to a pointer. Far from being a defect we see this as an advantage, for it opens the door to functions taking an array as an argument. it could be like this:

**int** sum\_points(**int** points[:6]);

**double** determinant4(**double** A[:4][4]);

**int** **main**(**void**){

 **int** s, points[6];

 **double** x, A[4][4];

 x = determinant4(A[]);

 **return** sum\_points(points[]);

}

### Restrictions for broken arrays before lvalue conversion

The discussion on margins showed that it is better to exclude an array with selection where the difference between one and the other choice (to keep margins or to drop them) would be made observable. It is also not a good idea to allow arrays with the first dimension broken where the semantics is different whether the array is trimmed or not (i.e., after and before lvalue conversion). In some situations it is only a broken first dimension that matters. The type and layout of an array before lvalue conversion is needed in particular in these contexts:

**typeof** operators

**sizeof**

**&** operator

### sizeof

**int** B[10][10];

**sizeof**(B[2:3]); // **sizeof**(**int**[3][10])

Long interpretation

**sizeof**(B[:][0:5]) // = **sizeof**(B)

**sizeof**(B[2:3][0:5][0]) // **sizeof**(**int**[10])

Short interpretation

**sizeof**(B[:][0:5]) // **sizeof**(**int**[10][5])

**sizeof**(B[2:3][0:5][0]) // **sizeof**(**int**[5])

However, in the long interpretation **sizeof** would yield a different result after lvalue conversion, agreeing with the values of the short interpretation.

Long interpretation

The operand of **sizeof** does not undergo lvalue conversion (6.3.2.1), but the dichotomy seems us worth enough to exclude broken arrays from the **sizeof** operand:

**sizeof**(B[2:3][0:5]) // **sizeof**(**int**[3][10])

**sizeof**(+B[2:3][0:5]) // **sizeof**(**int**[3][5])

Not all unbroken arrays should be allowed, though: there is a problem when either the length of the array or the expression L used for the selection is not an ICE. For example:

**int** A[2][n], B[2][5];

**sizeof**(A[:][0:3])**; sizeof**(B[:][0:n]); **sizeof**(B[0][0:n]);

Whether the three arguments to **sizeof** are unbroken or broken depends on the value of n. The problem does not arise if the selection is [:].

To avoid this, the range selections in the array should be restricted to [0:L] with L an integer constant expression or [:], and in the first case, if not the outermost selection, that the array on which the selection is operating be a fixed length array. But if [0:L] is not the outermost selection the user can and should simply omit the selection. Since allowing those selections would complicate the wording for **sizeof** for little gain if at all, we do not allow such not-outermost selections.

The text on the allowed arrays with selection as operands of **sizeof** finally would read (in case the long interpretation had been chosen):

*If its operand is an lvalue and is an array carrying a selection, it shall be of the form* A[R]E *where* A *is not an array with a nonempty selection,* [R] *is a range selection of a form other than* [B:L:s], *and E is empty or a succession of range selections of the forms* [], [:] *or* [::]*.*

Note that the selections [], [:] or [::] which follow [R] can be ignored by the translator; they do not affect the result of the **sizeof** operator. Also, we had to take care not to exclude arrays with selection which have already undergone lvalue conversion.

This wording excludes a selection like B[:][0:5][0] with B as above, which is an array carrying a one-dimensional, unbroken selection. Allowing an array subscripting expression which results in an array with selection complicates the wording, again for little or no gain. The user should simply write in this case B[0][0:5], which is always allowed as the operand to **sizeof**, whether B[0] has length 5 or more.

If the **sizeof** is part of the replacement text of a macro, that macro cannot control the way the argument is passed to it. For example, it cannot preclude B[:][0:5][0] in place of B[0][0:5]. But in macros even more that directly in the code, calling **sizeof** on its argument is more dangerous, because of the dependence on the lvalue conversion, for example

**sizeof**(A[:][0:3]) vs. **sizeof**(+A[:][0:3])

and because the array passed to the macro may or may not be broken.

If a writer of a macro wants to apply **sizeof** to its argument whatever it be, what is needed is a mechanism for making an array forget its selection. For example

**sizeof**(**\_Unselect**(x))

But it may be that it is the size after lvalue conversion what the macro wants. See the section “typeof, sizeof, \_Unselect() and \_Value()” in “Further extensions”.

Short interpretation

The value “returned” by the **sizeof** operator is the same before and after lvalue conversion. We allow arrays with selection as operands to **sizeof** unconditionally. The size of A[B:L] and A[B:L:s] is always *l*\***sizeof**(A[0]), where *l* is the value to which L evaluates.

If *s* is zero, the size in memory is **sizeof**(A[0]), not *l*\***sizeof**(A[0]). We prefer to keep the value which sizeof yields as *l*\***sizeof**(A[0]). This means that for these arrays **sizeof** does no return the number of bytes the object takes in memory. But returning this latter value would constitute an exception to the rule *l*\***sizeof**(A[0]), i.e., **\_Lengthof**(A)​\***sizeof**(A[0]); and this would bring in many problems: The value given by **sizeof** would not be the size needed to store the value in some other object; **sizeof**(A[B:L:s]) would no longer be an ICE whenever L is, but both s and L need be integer constant expressions, and **sizeof** would not return the same value for all objects of type *T*[*l*].

### & operator

Long interpretation

In a first version we chose the resulting expression to be a pointer to the full array, the selection being forgotten. This is because the purpose of selecting elements is to perform a range operation, which is not the case if the **&** operator is applied to the array with selection:

**int** A[10], B[10][8];

&A[3:5] // **int** (\*)[5], points to A[3]

&B[:][0:2]; // **int** (\*)[10][8]

&B[5:5][0:2]; // **int** (\*)[5][8], points to B[5]

&B[5:5][0:2][0]; // **int** (\*)[8], points to B[5]

We think it could be interesting to allow the addressof operator to construct a pointer that can address the selected multi-dimensional subarray. So as not to close this possibility for the future, we disallow the **&** operator.

Short interpretation

A pointer to a broken array addresses an object with a different memory layout as a pointer to a plain array. Therefore, it must carry the broken qualifier; i.e., it is a pointer to a broken array. This is consistent with the way qualifiers work.

The pointer needs to remember the memory layout of the array it points to; i.e., the exact way the array is broken. This memory of the layout is copied with the value:

**int** B[10][8], C[6][4];

**int** (\*p)[5][**broken** 2], (\*q)[5][**broken** 2];

**typeof**(p) p2; **typeof**(q) q2;

p= &B[0:5][0:2];

q= &C[0:5][0:2];

&p[1][0] - &p[0][0]; // 8

&q[1][0] - &q[0][0]; // 4

p=q;

&p[1][0] - &p[0][0]; // 4

Thus, allowing the **&** operator on broken arrays would require the enlargement of the type system; brokenness would no longer be an ephemeral property of some arrays with selection with no impact in practice on the programmer or even on implementers. And consider for instance function parameters: A parameter declared as **int** (\*p)[**broken** 2] does not determine the layout of \*p. The compiler would need at runtime the hidden data carried with a broken pointer in order to compute the address of (\*p)[1].

This is more than the present proposal intends. Therefore, we disallow the **&** operator. It may be interesting to add this in the future.

### typeof

Long interpretation

In the first place we restrict to operand to **typeof** in the same way as the operand to **sizeof** so as not to close the door for a future change in the meaning of **typeof** for broken arrays (which exist only before lvalue conversion) and to avoid a result that may depend on choices that may change (e.g., margins): **typeof**(x[2:6:2][0:5]) y;

In **typeof**, in addition, it may be decided in the future that its result remembers the selection. This is almost as making arrays with selection a different type than the full array. This is not the semantics of the long interpretation, where we want broken arrays to have the same type as the corresponding full array and let the semantics of the selection be taken care of by the concept of “carrying a selection”. If it were remembered, it should then be ignored in contexts where it cannot apply, as in a declaration:

**typeof**(x[:][0:5]) y;

But what to use **typeof** for if not a declaration or the type of a compound literal? For a cast. A cast is applied to a value, not to an lvalue, so here arrays with selection that change their number of elements after lvalue conversion are even more inadequate in **typeof** than in, say, **sizeof**:

(**typeof**(A[0:n:2])) A[0:n:2]; //Different types

Furthermore, if the programmer wants to recover the selection, this can easiliy be donce because the result of a cast is not an lvalue (hence, it consist of only the elements that had been selected), by applying [:] or [::]:

(**typeof**(+A[:][0:5]) A[:][0:5])[::]

f(n, ((**typeof**(y[0:n])) y[0:n])[:] )

So in the end we decided to allow the operand to the typeof operators in the same cases as it is allowed for the **sizeof** operator, and the result is the type of the expression with no selection.

Another reason for preventing for the time being the application of typeof to an array carrying a broken selection is that it may be to the type after lvalue conversion that it is more useful to apply the operand. That cannot be achieved by applying a trick for enforcing lvalue conversion:

**#define** typeofl(x) **typeof**(+(x))

typeofl(x[:][0:5]) y;

for it will also apply integer promotions and is only possible if the selected elements are singletons of arithmetic type.

Short interpretation

Since we do not want to extend the type system we sould not allow **typeof** on broken arrays, or if allowed the broken pseudo-qualifier should be dropped. This will make **typeof** inconsistent in the event that **broken** is fully integrated into the type system, allowing pointers to broken objects to be declared and constructed. For this reason we allow **typeof** in the same cases as **sizeof** is allowed in the long interpretation; namely, unbroken arrays that are known to be unbroken during the translation of the expression (i.e., the brokenness or not of which only depends on ICEs). **typeof\_unqual** is allowed on any array with selection, be it broken or carrying a stepped selection with step zero.

### \_Lengthof

Long interpretation

The restriction for the operand would be similar to that of **sizeof.** However, here it is only the outermost dimension which matters.

Furthermore, the question arises of what we want **\_Lengthof** to yield: the total length or the number of selected elements. This alternative arises in the long interpretation; in the short interpretation the only possibility is the number of selected elements, for in that case it is also the total number of elements. This possibility of two results in the long interpretation is not the same situation as in **sizeof**. Here it is clear that we want the total size; the reason not to allow a broken operand in **sizeof** is that that size will change upon lvalue conversion and that it is not clear what *the user* wants. He may be calling **sizeof** passing a broken selection and expect the operand to give him the size of the selection, not counting unselected elements. If, for **\_Lengthof**, we settle on the number of selected elements, no restriction would apply to its operand.

To return the number of selected elements is our preferred option. An lvalue is short lived, and we see no possible use of the length of it including the unselected elements. Furthermore, with this interpretation it is possible to use **\_Lengthof** on an operand whose outermost dimension was some inner dimension but has been exposed to the outermost one as a result of array subscripting, without the result depending on whether margins are retained or not when array subscripting is applied. It is also the sensible choice for multidimensional indexed or direct selections, to be explored below.

Therefore, for this operator, we resolve to let it return, in the long interpretation, the number of selected elements of the outermost dimension (i.e., of elements of the array proper), whence no restriction applies to its operand.

Since we insist in making A[] always equivalent to A, **\_Lengthof**(A[]) should return the same as **\_Lengthof**(A) and not 1, which seems and ad hoc exception. But it is not: **\_Lengthof** returns the number of selected elements from the first dimension, or the number of all of them if there is no selection there. And indeed A[] carries no selection in the first dimension. If it were so, a further selection A[][B:L] would select from the second dimension, which it does not.

We may say that A[] carries a selection in its 0-th dimension, if we start counting dimensions from one. This dimension has a single element, which is the whole matrix. As with any element, its elements run along those of the next dimension. Thus, the elements of A[0][0], which is an element form A’s second dimension, vary along A’s third dimension; those of A[0] run along A’s second dimension, and those of A[], which are those of A, run along A’s first dimension.

But we would place a note in the wording pointing out that an array carrying an empty selection carries no selection in its first dimension, had we chosen the long interpretation.

Short interpretation

Here the number of selected elements equals the total number of elements, and consequently there is no doublt as to what **\_Lengthof** should yield.

### Other Restrictions

An array with selection should not be allowed as the argument passed to a function: it cannot and should not decay to a pointer. In places where the object is needed for its type, an array with selection is strange: the intent of range selections is to select several elements from the array, to be operated, not to place the array inside **typeof**(), say. More generally, whenever the array with selection would be placed in a position where the action would not be to operate individually on the selected elements, i.e., where it does not act *as a range of objects* in our terminology, its use is questionable. We have identified these places:

**Argument to function**

**\_Generic,** controlling expression

**auto,** initializer for a type inferred declaration

**alignof**

**[*k*]** operator

**unary \***

In addition to **typeof, sizeof, &** and **\_Lengthof** treated above, and **casts** teated below. Of these, we have chosen to allow **\_Generic, auto, [*k*]** and **alignof**, though the latter case cannot arise.

#### \_Generic

Since it is the type of the controlling expression which is needed, there seems to be no reason for selecting elements from the array. This by itself is no reason for forbidding its use here, but we would do so so as not to make the code depend on broken arrays being of the same type as the corresponding full array, as is the reason for forbidding them in **typeof** in the long interpretation.

But the controlling type of a **\_Generic** selection is taken from its controlling expression after lvalue conversion, so this wariness does not apply. Indeed, since arrays with selection do not decay to pointers, they are a way of making the controlling type an array type, which is not possible with arrays not carrying a selection.

There is no need to any change in the wording for this operand. Arrays with selection would be allowed there. In the long interpretation their unselected elements are lost after lvalue conversion; in both interpretation brokenness is lost; in any interpretation the array type is preseved.

#### auto

The situation is similar as for **\_Generic**: the type is taken from the initializer after lvalue conversion. Here we are more interested in allowing arrays with selection, for it makes sense that it is the number of selected elements what we are interested in, and because it is the only way of declaring an identifier with array inferred type:

**int** A[10][6];

**auto** p = A; // int(\*)[6]

**auto** a = A[::]; // int[10][6]

**auto** b = A[0:5][3:3]; // int[5][3] (short interp.)

#### alignof

**alignof** can only be that of the corresponding full array, and in any case this operator only takes a type name, not an expression.

#### [*k*] operator

The [*k*] operator presents the ambiguity in the long interpretation of whether to start counting from the 0-th element of the array or form the first selected one. We have already argued that the latter choice is the right one.

#### unary \*

This is impossible, since the array with selection should not be convertible to a pointer.

### Macros, selection forgetting and lvalue conversion

Long interpretation

Many of the cases that needed careful consideration above will not arise in practice. Why would a programmer write

**typeof**(+A[6:3][0:5]) B;

instead of

**typeof**(A[0][0]) B[3][5];

? The latter has the advantage that integer promotions are avoided. Similarly, if the user wants the size of A[6:3][0:5] after lvalue conversion, he can just write

3\*5\***sizeof**(A[0][0])

And if he wants the size before lvalue conversion he should write **sizeof**(A[6:3]) or 3\***sizeof**(A[0]).

Both interpretations

For plain arrays, **typeof, sizeof** and **\_Lengthof** are useful because the array may be declared in one place and the operand used in another place where the declaration is not visible (in the literal sense). An array with selection is used on the spot. Why would someone write

**\_Lengthof**(A[0:n:3])

? The value is either n or 3\*n-2, depending on what is desired.

These situations arise only in macro definitions. For example, to write a macro that selects the first three elements of an array:

**#define** invert3(x) (x)[0:3] = 1/(x)[0:3]

If the array x passed to the macro already carries a selection of singletons (e.g.: **float** x[10]; invert3(x[5:5])), the macro will fail. Instead of providing in the language some operand to forget the selection, the best solution is probably to write the macro as above and do not pass to it an array with selection in its innermost dimension:

**float** \*p, x[10][6];

invert3(p); // O.K.

invert3(x[:]); // O.K.

invert3(x[:][:]); // Wrong

Likewise, if a macro wants to set to zero its argument x:

**#define** setzero(x) memset(&(x),**sizeof**(x),0)

it will fail if x is an array carrying a not-outermost selection of type [B:L] or a selection [B:L:s] anywhere. Far from being a defect, this is a safe behaviour: What would the caller want in those cases? To set to zero the whole matrix or just the selected elements? If he wants the whole matrix there is no reason for passing the matrix with a selection to the macro, except for a selection in the first dimension in case he wants to cut down the matrix; but in this case the macro does work: setzero(A[0:n]). If just the selected elements are wanted, the way to do it is using the range operations!

A[0:n:2]=0;

If the macro knows its argument will be a matrix, using ragne operations is also the right way to define it:

**#define** setzero(x) (x)[::]=0

This will set to zero only the selected elements of x, if they are singletons, the singletons from x’s selected elements if they are arrays, or the whole matrix if there is no selection.

Therefore, the cases where a macro cannot attain complete generality with respect to the type and selection carried by its argument are in the first place very rare (a multidimensional selection need be present, or a user passing an array with a selection that the macro wants discarded, in which case the users should have simply passed the array with no selection), and the failure of the macro appears as a safety valve rather than a limitation of the same.

For this reason there does not appear to be a need for the introduction of one operator for forgetting the selection and another one for forcing lvalue conversion (avoiding, e.g., integer promotions). We explore them in “Further extensions”.

## Casts

### Restrictions

Casts apply to values, not to lvalues. This simplifies the design. In the long interpretation, we’d like to restrict the cast operand in the same way as the **sizeof** operand, and since arrays with selection which are not lvalues are allowed there without restriction, there is no restriction in the operand to a cast. Also, there is no need to leave the possibility open for a pointer type in the cast that would result in a pointer addressing only the selected elements, as we did for the & operator, since after lvalue conversion all elements are selected, and even more fundamentally, a value of array type cannot be cast to a pointer to its address because it has no address.

At present the type name of a cast cannot specify an array type. This is because it cannot possibly apply to an array, which would be the only type that could be meaningfully cast to an array type. An array is allowed as the operand, but it decays to a pointer. As we now have arrays which do not decay, these should be allowed to be cast to arrays.

### Changing the singleton type (I)

The only obvious type a value of array type can be cast to is its own type. A cast changing the singleton type would also be meaningful:

**double** A[4][4];

(**float**[4][4]) A[::]

This can be used to prevent warnings from the compiler:

**float** A[4][4], B[4][4], C[4][4];

A[::] = (**float**[4][4])(B[::]+C[::])[::];

The last [::] is there because we want the cast to forget the selection. The reason is the the cast is to an “array of four arrays of four float”, and there is no selection in that expression; i.e., in the type written within (). Also, this choice adds felxibility, since the user can apply any selection he wants to the result of the cast. In particular, the selection before the cast can be recovered by writing [::] or a series of [:].

At first we didn’t include these casts in the present proposal, because it seems it requires the compiler to make a copy of the object, transforming each of its singletons. Later on we changed our design. This will be explained soon below.

### Redimensioning cast

An array may be cast to an array of the same singleton type and less or equal total size:

**float** A[4][4];

(**float**[2][4])A[];

This allows a multidimensional array to be treated as a vector, as in the following example for bidimensional arrays (in the absence of **\_Lengthof**, len2() had better been defined as **sizeof**(x)/**sizeof**((x)[0][0]) ):

**#define** len2(x) **\_Lengthof**(x)\***\_Lengthof**((x)[0])

**#define** VEC(x) ((**typeof**((x)[0][0])[len2(x)]) (x)[]);

**float** A[n][3][k], (\*B)[k];

**#define** Ã VEC(A)

**for**(**int** i=0; i<3\*n; i+=3) B[i][:]=Ã[i][:];

Note however that the reverse assignments are not possible: the result of a cast is not an lvalue.

The casts of this type that make more sense are the ones collapsing several dimensions into one, splitting one dimension into several ones or restricting the outermost length. But we do not see why other combinations should be prohibited, as long as the size of the target type is ≤ the size of the operand. The compiler may warn upon conversions that break the dimension layout:

**int** A[6][6];

(**int**[7][5])A[]; //Possible warning

(**int**[3][12])A[]; //Possible warning

(**int**[15])A[];

(**int**[2][3][6])A[];

### Changing the singleton type (II)

Coming back to casts that change the singleton type, consider

A[:] = (**float**)B[:];

A programmer writing this expresses the intent that he wants each value of B to be converted to **float**. This per element conversion avoids the copy required by casting the whole array. For this to be possible we have to make the cast operation a range operation. At first this seemed strange, but considering use cases we realised that not only it is useful but that it is going to be by far the most common use:

**int** \*A;

**unsigned int** \*s;

A[0:n] += (**int**)s[0:n];

for example.

We therefore changed radically our original design for casts. By making it a range operation it gains in expressivity, just as the == operator (see below). Unlike for this operator, we allow the array to which it applies to carry only the two extreme kinds of selection: either its selected elements are singletons or it carries an empty selection. The intermediate cases appear of very limited use. In the former case we have the redimensioning cast of our original design, that now requires the array to which it applies to carry the [] selection, no other one is valid. In the latter, the type of the cast can be anyone that is allowed for the singleton. We refer to these two casts as the *array cast* and the *range cast*. If intermediate selections were allowed these would be of array type, so that the compiler need not create a copy of the object and the effect would be to just reinterpret its dimensions.

If B is of type **double**[4][4], the type of an expression like

(**float**)B[::];

is **float**[4][4]. What then, is the advantage from the point of view of the translator with respect to our first design of (**float**​[4]​[4])B[::]? The advantage is that in this latter case the selection is forgotten, which result in a plain array of kind [4][4] for which the compiler may need to reserve space in memory; for instance, selections can be applied to that array. In the cast (**float**)B[::] the result is an array carrying a selection of singletons. This result will be used in one of the following ways: ignored; in a place where the value of the singletons is not needed (e.g., in **sizeof**), or as an operand of a range operation, where each element will be operated at a time (or in groups of four to take advantage of vector instructions, say), and the compiler knows it can convert the values one by one as they are being operated. Hence, no copy for it in memory is needed.

#### Variants of the element type in the cast

In an array cast we allow casts to an array type with a compatible type for the singletons. This is more restricted than a compatible array type, which includes variable size arrays of any size (the requirement for two array types to be compatible only mandates the sizes to be the same if both are given by integer constant expressions). We also allow any qualified or atomic version of the type, as for any other cast; these qualifiers and being atomic are lost in the cast.

### The selection after the cast

Our original design where the cast forgets the selection is flawed in one respect: a value of array type without selection cannot exist. If it did, it would have to decay to a pointer in many situations, which is impossible since a value hasn’t got an address. Therefore the result of an array cast must be a matrix which cannot decay to a pointer; i.e., a matrix carrying an empty selection. In the range cast we finally designed, the result of the cast carries a selection of singletons, and in the array cast the result carries an empty selection, as we have already explained.

## Assignments

### Assigning an array

We allow the following:

**int** A[3][4], B[4];

A[:] = B[]; //Equivalent to A[0][:]=B[:], A[1][:]=B[:], etc.

If the left operand carries a selection where the selected elements are arrays, the right operand must be an array matching the dimensions of those selected elements and with a 0-dimensional selection, to prevent it decaying to pointer, as here. We do not allow the right operand to carry a (>0)-dimensional selection:

**int** C[2][3][4] A[3][4], B[4];

A[:] = B[]; //Allowed

A[:] = B[:]; //Not allowed

C[:] = A[]; //Allowed

C[:] = A[:]; //Not allowed

C[:] = A[::]; //Not allowed

C[:][:] = A[0][]; //Allowed

C[:][:] = A[0][:]; //Not allowed

C[:][:] = A[0][:]+B[:]; //Not allowed

C[0][0][:] = A[0][:]+B[:]; //Allowed, singletons

C[:][:] = C[0][0][]; //Not allowed, for different reason

If we want to copy the result of A[0][:]+B[:] into each C[*i*][*j*] we need an intermediate variable or forgetting the selection, if it were possible. The latter would require selecting again with [] to prevent the matrix from decaying to pointer:

int D[4];

D[:] = A[0][:]+B[:];

C[:][:] = D;

C[:][:] = **\_Unselect**(A[0][:]+B[:])[]; //Suposing it existed

We do allow a right operand matching the whole left array.

**int** A[3][4], B[3][4];

A[:] = B[:];

A[::] = B[::]; //Equivalent to this

The reason we do not allow the ones above is that code using that can be very confusing to read and understand. It is not clear whether the right array is being assigned to each selected element (of array type) at the left (the 1st case), as the not allowed A[:] = B[:] above, or whether it is a per-element assignment as A[:] = B[:] here, (the 2nd case). With our choice for what is allowed and what is not, the 1st case is always identified by the right operand carrying an empty selection, []. The 2nd case by having a range selection.

In the 1st case the selection [] is needed just to prevent the array decaying to a pointer:

A[:] = B[];

We cannot just say in a situation like this that B without a following [] does not decay to a pointer, because we may want it to decay, if the type of B[0] is compatible with the element type of A (i.e., fill all elements of A with the address of B[0]).

Therefore, when we said above to define the 1st case “the right operand must be an array matching the selected elements with no selection or with a 0-dimensional selection”, the possibility “with no selection” cannot arise, because there is no way of preventing an array in that position to decay to a pointer than to apply an array selection on it.

### Assigning into an array

We considered allowing the assignments in the right columns as synonyms of those at the left:

**int** A[3][3], B[3][3], C[3][3], D[3];

C[::] = A[::] - B[::]; C = A[::] - B[::];

D[:] = (A[:] == B[:]); D = (A[:] == B[:]);

D[] = A[0][]; D = A[0][];

But we want range operations always to involve matrices with selections or singletons: if one operand carries a selection then the other operand either carries a selection or is operated with each of the elements selected from the first operand. Therefore, of the forms at the right column we only allow the last one (where the “first operand” is A[0][], with just one selected element, namely A[0], and the “other operand” is D).

### Overlapping in assignment

We do not allow expressions like

A[0:8] = A[1:8];

A[0:5] = A[4:5:-1];

A[0:8] = A[0:8]\*A[3];

A[0:5] = A[0:5] == A[5:5]; //Assignment of a single value into five places.

The text on assignment expressions already includes the following requisite:

*If the value being stored in an object is read from another object that overlaps in any way the storage of the first object, then the two objects shall occupy exactly the same storage and shall have qualified or unqualified versions of a compatible type; otherwise, the behavior is undefined.*

This makes undefined the first of the following assignments, but no the second:

**union** {**int** i; **short** j} a;

a.i = a.j;

a.i = a.j + 0;

In the second assignment, the value stored in a.i is not read from an *object,* but is the result of the expression a.j+0.

For range operations we need be stricter, in order to make possible for those operations to be translated into vector operations in machine code. For example,

A[0:8] = A[8:8]\*B[0:8];

A[0:8] = A[1:8]\*B[0:8];

In the second assignment, the vector instructions may not produce what is written.

For this reason we require that no element which is written to is read at the right of the assignment operator, except for the computation of itself. Thus, the first two below are allowed but the next two are not:

A[0:8] = A[0:8]\*A[0:8];

A[0:8] = A[0:8]\*A[8:8];

A[0:8] = A[1:8]\*A[1:8];

A[0:8] \*= A[3];

The condition that an element not be read has to be understood in the abstract machine. For example, in

A[0:8] = B[0:8] + 0\*A[1:8];

the implementation may choose not to read A[1:8], but in the abstract machine it is read and the behavior is undefined.

Whether some “forbidden” element is read at the right might depend on input, or on the code of a function unknown to the translator, as in

A[0:8] = f(A);

The wording of the condition needs not adjustment. If, during execution, no forbidden element is read, the behavior is defined; otherwise, it is not. If, had the program been translated according to the abstract machine, some forbidden element would have been read, but it is not according to how the program was actually translated, then the behaviour the program exhibits is right under any possible interpretation. It may happen that the elements read depend on some input that in turn depends on how the program is exactly translated, but that is already the case for constructions existing in the language:

p[3]++ + f(p)

Here f may end up reading some or other element from the array pointed to by p depending on some input.

#### Overlapping in the range

We can also make undefined any overlapping in the range expressions with the array being assigned to:

A[0:A[0]] = 6;

The translator must evaluate L and B (as in A[B:L]) before translating the assignment, so the construction does not seem problematic. The situation gets more complicated if A[0] is also used at the right:

A[0:A[0]] = A[0:4]\*2;

For this instruction to have defined behavior A[0] has to be 4 before the assignment, which means that it will be eight after the assignment, but there is again no ambiguity.

In the previous examples, the program will exhibit a different behaviour if the translator translates it as follows: First compute all values of B’s present in the instruction; then compute and assign the first value in the range assignment (which does not depend on the values of L or s); then evaluate the expressions L’s and s’s and compute the rest of the assignment.

We don’t think the previous is a desirable behaviour. We therefore would mandate evaluation of B, L and s before the range selection and don’t restrict them as regards overlapping with the object being assigned to. Actually, there is no wording needed for this. The standard already includes

*The value computations of the operands of an operator are sequenced before the value computation of the result of the operation.*

The value of A[*b*] is part of the result of the operation A[B:L] or A[B:L:s]. Hence, the translator is required to evaluate B, L and s, which are operands, before evaluating A[*b*].

There remains the unspecification of whether the left or the right operand is evaluated first, and this may cause undefined behaviour because of side effects in the expressions in the range, just as for any other assignment instruction.

## Other

### The decaying of arrays to pointers

The subsection of the standard on additive operators includes the following constraint:

*For addition, either both operands shall have arithmetic type, or one operand shall be a pointer to a complete object type and the other shall have integer type.*

So, the operand cannot be an array, which we know it can. The text at **6.3.2.1** on arithmetic conversion says that

*Except when it is the operand of* [...] *an expression that has type “array of* type*” is converted to an expression with type “pointer to* type*” that points to the initial element of the array object and is not an lvalue.* [...]

But it is dubious that this text combined with the restriction allows an array as the operand of the additive operator. It depends on whether we consider the expression at the left of the + operator (say) to be directly the operand of the + or whether the conversion first applies, thence it is the resulting pointer which is “seen” by the + operator. The conversion does not take place irrespective of the operator the array *is an operand of*; hence, the array is an operand of the operator in question. Note that the semantics does make explicit that *if both operands have arithmetic type, the usual arithmetic conversions are performed on them,* hinting at the need of an explicit mention of arrays as a possible operands. The admitted reading is that it is not needed.

Whatever interpretation one chooses, with the introduction of arrays with selection, which are not converted to pointers, the text at the operator subclause must be explicit.

This also prompted the redefinition of the [*k*] array subscripting operator, which is no longer defined as equivalent to (\*((E1)+(E2))). This description could be preserved with extra wording, either specifying a conversion of the array with selection to a pointer, which goes against its intended use, or preventing it to apply to arrays with selection and inserting a description for the later directly in terms of “selects the *n*-th element”, which would leave a strange asymmetry: “why not apply the direct description also to arrays which have no selection?”, would think a reader of that text.

The redefinition of the [*k*] operator is needed for other, unrelated reasons. Because of this, this redefinition was moved to an independent proposal and the proposed wording here assumes that to have been already integrated into the standard.

### Literal 0 promoted to pointer

In a conditional operation, a common type has to be defined for the second and third operands. For this to be possible the types of those operands need be compatible or some rules have to be defined in case they are not. The latter happens for null pointer constants, pointers in general and pointer to **void**. All combinations are possible except an ICE with the value 0 and the value **nullptr**. For arrays, we will require that the singletons of one and the other operand could be the operands themselves and define the common type accordingly. We exclude the combinations that need the value of the operand, not just its type; that is, we exclude an ICE with the value 0 as possible match to a pointer or other null pointer constant (except, of course, if they match as integers, not as null pointer constants). The constant (**void**\*)0 need not be excluded because in any combination where it is allowed as null pointer constant (i.e., taking into account its value, not just its type) it is also allowed for its **void**\* type.

The following are not allowed, amongst others:

**constexpr int** A[3] = {0,0,0};

**constexpr void** \*B[3] = {NULL, NULL, NULL};

1 ? A[:] : B[:];

1 ? (**int**[3]){0,0,0}[:] : (**void**\*[3]){NULL, NULL, NULL}[:];

The reason for not allowing this is that the reason for allowing them for scalar values is missing. They need be allowed for scalars because 0 is a common way of indicating a null pointer, so that, e.g., the following should be allowed:

p == q ? p : 0;

p == q ? p : NULL;

In the second line NULL might have been defined to 0. But in the example above A is declared as an array of integers, so the values 0 it contains cannot be pointers. If the programmer wants those kinds of combinations both arrays shall be declared with elements of pointer type. E. g.,

**float** \*A[3], \*B[3], \*C[3];

A[:] = (**float** \*[3]){&a, &b, &c};

B[:] = (**float** \*[3]){NULL, NULL, NULL};

C[:] = x > 0 ? A[:] : B[:];

We also exclude those combinations for the assignment operator in case the right operand is an array. Thus, the first assignment below is valid but the second one is not:

**void** \*A[3];

A[:] = 0;

A[:] = (**int**[3]){0,0,0}[:];

A similar criterion is followed for the equality operators: if both operands are arrays with selection the restriction is the same as for the conditional operator. If one is an array with selection and the other is a singleton the latter may be a null pointer constant of integer type in case the array’s singletons have pointer type or type **nullptr\_t,** but the opposite is not allowed: if the singleton operand has pointer type or type **nullptr\_t,** so must have the singletons from the array. The latter is also required in assignments but needs no extra wording because the combination of a left operand of integer type and right operand of pointer type or type **nullptr\_t** is already not allowed.

### Mixing arrays with selection and arrays which decay to pointers

We do not allow the following:

**int** \*A[3], B[3];

A[:] - B; //Would be {A[0]-B, A[1]-B, A[2]-B}

This affects the operators -, <, >, <=, >=, = and -=. If the programmer wants this, the code should be written thus:

A[:] - &B[0]; *or* A[:] - (**int**\*)B

A[:] = &B[0]; etc.

A[:] < &B[0];

It seems to us that allowing the mixing would be a source of bugs. The workaround, as shown in the examples above, is straightforward.

### Arrays with selections of different number of dimensions

We allow them as in the third assignment below:

**float** A[4][4], B[4][4], C[4], f;

A[::] \*= f;

A[::] += B[::];

A[:] \*= C[:];

In the first of the assignments above we have a matrix carrying a selection of singletons operated with a singleton. In the second one, two matrices carrying corresponding selections of singletons. In the third one, two matrices carrying selections of singletons but not matching.

When both operands are arrays carrying a nonempty selection the semantics is defined by saying that each of the corresponding selected elements are operated (the number of selected elements must be the same in one and the other operand). When applied to the expression A[::] += B[::], which is equivalent to A[:][:] += B[:][:], this implies that each A[*i*] is operated with each B[*i*], i.e., A[*i*][:] += B[*i*][:]. Since these A[*i*] and B[*i*] still carry selections, the rule applies again and we get that each A[*i*][*j*] is operated with each A[*i*][*j*]. When the rule is applied to the expression A[:] \*= C[:], we get again that each A[*i*] is operated with each C[*i*]. Now the first ones still carry a selection but the C[*i*] are singletons, and A[*i*][:] \*= C[*i*] means A[*i*][*j*] \*= C[*i*]; that is, each row of the matrix A is multiplied by the corresponding element in the vector C.

#### The equality operator

We have to consider how the rule above integrates with the allowed and disallowed assignments. All the cases considered in “assigning an array” are of left operands whose selected elements are of array type. If the right operand carries a 0-dimensional selection, the rule does not apply; if the right operand carries a selection which is not of singletons, application of this rule will eventually lead to assignments a = b where both elements are matrices of the same dimensions, which is allowed; or where the dimensions do not match, which is not allowed, or where b is a singleton, which is not allowed either (a[::] = b would be allowed, a = b not). In case the dimensions match (the first of the three cases just considered), the rule above gives wrong semantics, since in a direct assignment of a matrix without selection into a matrix, the former decays to a pointer. That is, in

**int** A[4][4], B[4][4];

A[:] = B[:];

application of the rule gives A[*i*]=B[*i*], which are A[*i*]=&B[*i*][0], but the assignments we want are A[*i*] = B[*i*][]. Since the assignment operator needs wording of its own, the rule will not apply to it.

If the left operand carries a selection of singletons, the rule gives the correct semantics.

Since arrays carrying a selection not of singletons are permitted only in a few places and the semantics is specific for each case (equality operators, assignment), we will state the general rule of recursive operation of selected elements only for the case the innermost selected elements are singletons.

### On modifiable lvalues

The definition of modifiable lvalue excludes arrays from it. If we look for “modifiable lvalue” in the standard we find the following instances, aside from the definition:

* postfix/prefix increment and decrement

*[...] arithmetic or pointer type, and shall be a modifiable lvalue.*

* *An assignment operator shall have a modifiable lvalue as its left operand.*
* errno

*which expands to a modifiable lvalue that has type int*

* Checked integer operation type-generic macros

*result shall be a modifiable lvalue of any integer type other than ...*

* stderr, stdin, and stdout

*are not required to be modifiable lvalues*

Therefore, the only use of the term that needs arrays excluded from modifiable lvalues is the one on the assignment operator. But that subclause lists the possible combinations for the types of left and right operands, and an array can never be the left operand. So,

*The exclusion of array from modifiable lvalues is not needed in the current standard*

Hence, it would be more appropriate to say that an lvalue of array type cannot be modified because there is no production in the language that will do it, than to say that they are not, intrinsically, modifiable.

Now we have arrays with selection, which can be the left operand of an assignment. The obvious adjustment to the wording was to exclude from modifiable lvalues only arrays not carrying a selection. But the preceding analysis shows that it is simpler to just drop the clause “does not have array type” from the definition. A further change is needed: it has to be required, for an array to be modifiable, that the singletons be modifiable lvalues.

This choice also accommodates better arrays at the left of an assignment as in E = B[], where E does not carry a selection. Otherwise, in order to allow the latter construction, the wording on the assignment operators has to be adjusted to include specifically arrays as possible left operands beyond modifiable lvalues, or to accept that they are allowed by saying that E= is equivalent to E[]=. Contrary to arrays decaying to pointer for, e.g., the addition operator, here the selection E[] does not transform the array into anything different. In short, it would be wrong to pretend that arrays without selection continue to be not modifiable. We do still say that E= is equivalent to E[]=, but this is just to be able to describe those assignments by the same words used for assignments where the left operand carries a selection.

## Complexity of implementation

### Graded complexity of array selections

The range selections proposed in this paper are graded in complexity of semantics and interaction with the current language. The following is an informal list of growing complexity or of dependency, later features requiring prior ones. In many cases there is not a growth in the complexity of implementation. Here, A does not include itself range selections, i. e. is an array without selection; [*k*] represents the array indexing operator; whenever [B:L] is present it is understood that [:] or [B:L:s] is also possible, and ICE stands for integer constant expression:

* A[B:L] with B, L and s ICE . [*k*] is allowed.
* A[B:L] with L and s ICE. [*k*] is allowed.
* A[B:L][B’:L’]... , L, s, L’, s’ ... ICE. [*k*] not allowed on multidimensional selections.
* A[B:L][B’:L’]... , L, s, L’, s’ ... ICE. [*k*] allowed when the second dimension is not broken (This dimension will become the outermost dimension of the selected array.)
* Like the above, with [*k*] allowed anywhere.
* A[B:L][B’:L’]... , L and s might not be ICE but only in inner ranges, not in the outermost dimension. [*k*] allowed when, in the the second dimension (which will become the outermost one of the selected array), L is an ICE.
* A[B:L][B’:L’]... , L and s need not be ICE. [*k*] allowed anywhere.
* A[B:L][B’:L’], where A[B:L] is an array of pointers.

Independent from these, the following restrictions on the value of s are also graded in difficulty of handling.

* s might not be zero.
* s might be zero only if L is an ICE equal to 1.
* s might be zero only if L is 1.
* s might be zero.

With respect to the broken character of selections, their length and the type of the selected elements, the following is an increasing list of allowed selections:

* A[R] where A is a unidimensional array not carrying a selection, R can have any form except empty and B:L:s and if it has the form B:L, L is an ICE.
* A[::] where A need not be unidimensional and if it carries a selection it must be of the above form.
* Like the above, with spurious [] and [::] allowed.
* [] and [:]
* [B:L:s] allowed in the first selection, with s an ICE of value 1 or -1.
* In addition, s need not be an ICE.
* L need not be an ICE.
* s and ICE, but need not be 1 or -1.
* Any other combination for the first selection
* Any other combination

This proposal includes all possibilities listed in the foregoing lists except the last one of the first list.

### What would be mandatory

As we noted in the introduction, small implementations are reluctant to adopt complex features, but at the same time the committee should strive to avoid divergence in the implementations, which requires standardising common extensions and, when possible, foreseeing it. The only way to achieve both goals is to standardise the features and at the same time allowing implementations not to implement them if they don’t want.

In the first place, we do not want too make range selections mandatory:

**\_\_STDC\_ARRAY\_SELECTIONS\_\_** Undefined or definded and expands to 0 if range selections are not supported; expands to 1 otherwise.

Note that we have written *range* selections. We intend to make empty selections mandatory. The reason we name it array\_selections and nor range\_selections is that other array selections are possible, though we do not provide wording for them (inexed and direct selections).

The established practice for feature test macros is to define the macro in negative terms:

**\_\_STDC\_N0\_ARRAY\_SELECTIONS\_\_** Defined to 0 if range selections are not supported.

This way, if in the future the feature is made mandatory, the macro can disappear. Actually, this can also be done if the macro is defined in possitive terms. If so, programs will need a test for the version under which they are being compiled if they want to test the availabitily of the feature, since lack of the macro can mean very old or very new version. But a definition in negative terms also requires a test for older version. In one case the version test is to distinguish before mandatory from after mandatory; in the other case, before existence from existance.

There may be a difference in the expression of intent; a negative definition seems to convey that supporting the feature is the default. We choose the possitive definition because we will be using the macro also for another purpose, where absence of the macro cannot possibly mean the new behaviour (see “Conflict with array subscripting” with respecto to direct selections below).

The different gradings above provide a hint as to the partial implementations of range selections that implementations may choose. Implementations defining **\_\_STDC\_​ARRAY\_​SELECTIONS\_\_** to one may be allowed to accept a partial set of possible combinations for the range. We propose the following optionality:

**\_\_STDC\_ARRSEL\_NESTED\_\_** Expands to 0 if selections of the form [B:L] and [B:L:s] can only be applied to expressions of pointer type and to arrays carrying no selection or an empty selection, and range operations are allowed only if the selected elements from the matrices treated as a range of objects are singletons. Expands to 1 otherwise.

**\_\_STDC\_ARRSEL\_STEPPED\_\_** Expands to 0 if stepped selections are not supported; to 1 if they are supported.

In addition, we have thought of another macro expressing parcial support:

**\_\_STDC\_ARRSEL\_CONSTANT\_\_** Expands to 1 if L and s need be integer constant expressions as well as B if the selection applies to an array already carrying a selection. Expands to 0 otherwise.

Here the values of 0 and 1 are reversed: The value 0 means more cases supported, the value of 1, not supported. The reason for this is that we are not including this macro in the present porposal. If later on it is introduced, a value 0 sould mean the same as its absence.

If the first two macros expand to 0 broken selections cannot arise. Furthermore, a value of 0 in the first macro means that a maximal sequence in the code of adjacent array selections either results in a selection of singletons or is an empty selection (i.e., [][]... []), except that a partial selection is allowed if it is used as the operand of some operator that treats it as a whole, namely, **sizeof** or the typeof operands. Such an implementation would allow comparisons of whole matrices as in A[] == B[] and assignments like E = B[], but not assignments like E[:] = B[], which is a range operation on the elements E[:], which are not singletons.

The reason why an ICE expression is not enforced for B in the outermost selection when **\_\_STDC\_​ARRSEL\_​CONSTANT\_\_** is 1 is that a variable base can be achieved even with B restricted to a literal 0, as in (A+n)[0:L]. This is equivalent to A[n:L], so mandating an ICE in place of B seems pointless. The reason why B is required to be constant in inner selections is that the restriction expressed by this macro means that all selected elements are at a translation time known offset from the base of the array (if not applied to an array with a VLA elment type).

A value of 0 for the first two macros constitutes a considerable simplification for the implementation with respect to the full set and yet it offers the programmer the most common use cases of range selections. It becomes even more useful if combined to casts that redimension the matrix:

**int** A[4][4][20];

((**int**[16][20])A[])[0:8];

More macros or more values for the proposed macros could be defined, but a fine grained possible support expressed via macros would be of no use if the programmer knows what his implementation supports, or a burden for the programmer if he wants to produce a strictly conforming program. In the latter case he may cut short and just test for none / partial in a specific form / full support, ignoring any other combination.

As regards a step zero, we gradually shifted our preferences from including it in **\_\_STDC\_​ARRSEL\_**​**STEPPED\_\_**, which could then take values 0, 1 or 2, to allowing the restriction (of not allowig a step zero) only in case the implementation suports only constant L and s, i.e., in case the macro **\_\_STDC\_​ARRSEL\_​CONSTANT\_\_** were 0 (by then we were including this macro in the proposal), to require the support for step zero whenever stepped selections are supported. This happened because of our thinking of how an implementation may translate range operations.

Another reason for not allowing more complicated yet partial implementations of the feature is that, if a translator finds a certain selection too complicated it can always translate it into a for loop. Thus, either provide a simple set of features or provide the full set.

The macro **\_\_STDC\_ARRSEL\_CONSTANT\_\_** becomes more significant when *direct selections* are included, one of the topics of the next section.

### How range selections might be translated

## Indexed and direct selections

### An array with selection as the index

As in the following example:

**size\_t** n, I[3];

**float** A[10];

I[] = ((**size\_t**[3]){0,n,n+1})[];

A[I[:]]; //{A[0], A[n], A[n+1]}

The reason for requiring the selection [:] after I is apparent when considering multi-dimensional arrays. Suppose we don’t require it and take the elements of the array placed inside [] as the indices (the first interprtation, which will be referred to later on):

**size\_t** I[4][2];

**float** A[8][8];

I = (**typeof**(I)){{0,3}, {2,2}, {4,1}, {6,0}};

A[I]; // {A[0][3], A[2][2], etc.}

A[I[0]]; // This should be A[0][3]

A[{0, 3}] // But is {A[0], A[3]}

Our first choice to provide all options and a coherent selection scheme was that a one-dimensional array specifies a sequence of indices to be applied to successive dimensions. Therefore, placing I as defined above inside an array selector [] has no meaning. If we want a series of elements to be selected we need to provide a range of arrays:

A[I[:]]; // {A[0][3], A[2][2], A[4][1], A[6][0]}

A[I[0:2]]; // {A[0][3], A[2][2]}

**size\_t** J[2] = {0,2};

**size\_t** K[2][1] = {{0},{2}};

A[J[]]; // A[0][2]

A[J[:]]; // {A[0], A[2]}

A[K[:]]; // {A[0], A[2]}

The last line has the displayed meaning because of the way we have defined [(**size\_t**[])​{0}]. The next to last line because of the way [0] is already defined.

The rule is: The selection A[I[R]] has as many elements as elements are selected in I[R].

This criterion also has the advantage that array subscripting operations, where the expression n in [n] has integer type, and array selections with an array as the index ​—which we will call *indexed* selections​—, can be distinguished visually. The latter will always feature a selection. The only exception is the selection of only one element, as in

**size\_t** I[3] = {2,1,1};

**int** A[4][4][4];

A[I]; // A[2][1][1], since a nondecaying I is equiv. to I[]

A[I[]]; // The same as above

A[I[0]][I[1]][I[2]];

The three selections are equivalent (later it is seen that they should not be equivalent; see the section below “Singleton or not”). We believe it is the third which should be used, not the first. Those are always available to the programmer.

### The kinds of matrices allowed as indices

The index matrix shall be one- or two-dimensional. More specifically, I[0] should be:

— of integer type; or

— A fixed length array whose element type is an integer type.

Furthermore, if the matrix is bidimensional it may not carry a two-dimensional selection.

Two- and higher-dimensional selections could be possible provided the type of the selected elements is one of the above, but it seems to us an unnecessary complication.

Appart from the type of the matrix we may restrict the form of the expression. We may forbid computed arrays, as in A[I[0:n]+J[:]/2]. This complicates the translation. If the array expression is given by an identifier of array type, to which possibly an array selection has been applied, the indices of the elemetns chosen in A are taken directly from an array, say I, A[*i*] needing I[*i*]. For example, the following instruction could be translated as shown:

A[I[:]] = B[:]+C[:]; //Assume the length is *n*

for *i* = 1..*n* A[I[*i*]]=B[*i*]+C[*i*]

But if the index is matrix is computed this is not possible. A compiler able to translate a range operation can place insde A[] the operation that yields the *i*-th element of the index matrix, avoiding the need to allocate memory for the computed index matrix:

for *i* = 1..*n* A[I[*i*]+J[*i*]/2]=B[*i*]+C[*i*]

It seems therefore that the complication is more apparent than real. But just in case it be desired to apply, at first, a restriction on the index matrix, we should think how to formulate it.

Our first idea was to require that the first token after the opening [ be an identifier. This would make invalid a valid expression by enclosing it in (). There is no case in the language where this happens for an expression. We may modify the requirement to say that “after all outermost pairs of matching () have been removed the first token is an identifier”. But this would leave out expressions like (I[0])[:]. We may strip all pairs of redundant parentheses, but that would still miss strings and compound literals. In the end we came to a wording which describes the possibilities for the expression after removal of outermost (), leading to a recursive specification, which is equivalent to saying that the expression must match *direct-array*, defined as follows:

*array-kernel: direct-array:*

( *direct-array* ) *array-kernel*

 *constant* (of array type) *array-kernel* [ *cond.-expr.* (of integ. type) ]

 *compound literal* (of arr. type) *array-kernel range-selector*

avoiding the definition of these two terms in the syntax.

Then we realised that a semantic definition is much easier. What we want in the end is that the indices be retrived from some array which already exists in memory. Thus, we may say that the index expression has to denote and object, or even better, that it has to be an lvalue.

#### Limit to nested indices

We may allow implementations to impose a limit on the nesting of indices in array selectors, listed on 5.3.5.2 Translation limits:

— 15 nesting levels of index arrays in array selectors

We were guided for this by the “12 pointer, array, and function declarators (in any combinations)” and the “63 levels of nested structure or union definitions”. We think that the latter is the one that best matches the case at hand, but at the same time see index nesting in selectors much less likely than nesting of structures.

### An array without selection, sometimes

While we argued that mandating the index to carry a selection facilitates visual discrimination of array subscripting and range selection, having to always type I[:] may be felt as a spurious nuisance. If I is two-dimensional there is no other possible interpretation for [I] (since we are precluding I[:][:]); also if the array to which the selection is being applied is one-dimensional, which will probably be the most common use. The programmer may tell apart easily a range selection of this kind from array subscripting by, e.g., using always a capital letter for the index matrix and a lowercase one for scalars, or by using only A,B,I,J for matrices that may function as indices, say.

Therefore, we propose that a selection in the index matrix be mandatory only if the matrix to which the indexed selection is applied is >1-dimensional and the index matrix is one-dimensional. Thus,

**size\_t** I[]={2,1}, J[][1]={{2},{1}},

 K[1][2]={{2,1}}, L={1,3,0};

**int** A[6], B[6][6], C[6][6][6];

A[I], A[J];

B[J]; // {B[2], B[1]}

B[K]; // B[2][1]

B[I[]], C[I[]]; // B[2][1], C[2][1]

B[I[:]], C[I[:]]; // {B[2], B[1]}, {C[2], C[1]}

C[L[]]; // C[1][3][0]

C[L[:]]; // {C[1], C[3], C[0]}

B[L[0:2]]; // {B[1], B[3]}

B[L[:]]; // {B[1], B[3], B[0]}

An implementation might relax this further to require a selection only if the number of elements of the matrix used as the index is ​≤ the number of dimensions of the matrix at the left, so that in the last of the examples above [:] would not be needed: B[L].

We have to be careful not to break the equivalence between I and I[]. Since, when A and I are one-dimensional, we have made A[I] equivalent to A[I[:]], so shall be the meaning of A[I[]]. We cannot say that in this case the selection of I is ignored because it is still needed if the programmer does not want all the elements in the index array to be selected:

**float** A[10];

**int** I[3]={0,9,3,6};

A[I[1:3]];

So we simply state that “if the elements of A are singletons the selection A[I] is equivalent to A[I[:]]”. Likewise if neither the elements of A nor those of I are singletons. So the rule reads

*if the elements of* A *are singletons or the elements of*I *are not
singletons the selection* A[I] *is equivalent to* A[I[:]]

### An array without selection, always

The previous rule leaves as exceptional the case when the elements of A are not singletons and the elements of I are. We prefer not to have this exception. This means that if the user wants to apply {2,1} as one-element bidimensional selection, he will need an extra {} surrounding; i.e., a bidimensional matrix as index:

**int** A[6][6], I[]={2,1}, J[1][2]={{2,1}};

A[I]; // Equiv. to A[I[]] and A[I[:]]. {A[2], A[1]}

A[J]; // Equiv. to A[J[]] and A[J[:]]. A[2][1]

*The selection* A[I] *is equivalent to* A[I[:]]

We have come round to the first interpretation, which we deemed wrong, but now we don’t think A[I[0]] should be A[0][3]:

I = (**typeof**(I)){{0,3}, {2,2}, {4,1}, {6,0}};

A[I]; // {A[0][3], A[2][2], etc.}

A[I[0]]; // {A[0], A[3]}

A[I[0:1]]; // Now this is needed to get {A[0][3]}

That the two last lines yield different results is not incoherent. I[0] is a 1-dimensional matrix while I[0:1] is a 2-dimensional matrix with only one element in its outermost dimension. Their types are *T*[2] and *T*[1][2] respectively. Similarly,

J = (**typeof**(J)){0, 3, 1, 2};

A[J]; // {A[0], A[3], A[1], A[2]}

A[J[0]]; // Array subscripting. A[0]

A[J[0:1]]; // {A[0]}

for J[0] is of type *T* and J[0:1] is of type *T*[1].

The relation between the number of elements of the index matrix and the number of elements of the resulting selection is now that they are equal. When we mandated a selection to be always present it equalled the number of elements selected. This is the same for nonempty selections, but is different for an empty one. Now we have

**\_Lengthof**(A[I]) = **\_Lengthof**(A[I[]]) = **\_Lengthof**(A[I[:]]) =

 = **\_Lengthof**(I) = **\_Lengthof**(I[]) = **\_Lengthof**(I[:])

And generally, **\_Lengthof**(A[I[R]]) = **\_Lengthof**(I[R])

R here may be empty, :, B:L, B:L:s or an indexed selection itself. It may be :: only if I is one-dimensional.

The relation between the number of dimensions selected from A, which we will call the *depth* of the selection, and the index matrix is that the former is the number of elements of the elements of the latter; i.e., of R[0] in our notation. In the selection A[I[0]] the index matrix is I[0], and I[0][0] are singletons. In A[I[0:1]] the index matrix is I, and its elements are bidimensional arrays: I[0], which is I[0:1][0].

### The type of the selection

The type of a selection of the form A[R] where R is a matrix is obvious after lvalue conversion. If the elements of R are arrays of length *m*, or singletons in which case we let *m*=1*,* and they are *l* in number (the selected ones. In any case, R undergoes lvalue conversion), the selection has depth *m* and consumes *m* dimensions from A, and the type is

**typeof**(A[0] . . . [0])[*l*]

where there are *m* [0]’s. Equivalently, if the type of A’s singletons is *T* and A has *n* dimensions,

*T*[*l*][*l*(m+1)] . . . [*l*(n)]

Long interpretation

The type before lvalue conversion is not that clear. The values of multidimensional selections in R (the length *m* arrays above) can be mixed and repeated in any way. One may choose to impose immediate lvalue conversion of an indexed selection; that is, an indexed selection expression is not an lvalue. This is not a good choice because it precludes one good use of indexed selections:

**float** A[10], B[4];

**int** I[3]={0,9,3,6};

A[I]=B[:];

Before lvalue conversion, the selection expressed by A[R] is contained in the object referred to by A and there may be holes. This is just as for range selections. Repetitions are part of the selection, but the repeated elements do not appear twice in the object, as is the case for a stepped selection of step zero. There is no other choice, since if it is still an lvalue we have to keep it inside A. The first *m* dimensions (continuing with the notation above) are broken in an irregular way.

We can make the resulting array with selection less complicated if we collapse the first *m* dimensions. Continuing with the notations above, the types of A and of the indexed selection are respectively:

*T*[*l*(1)] . . . [*l*(m)][*l*(m+1)] . . . [*l*(n)]

*T*[*l*(1)*×l*(2)*× ·* *·* *· ×l*(m)][*l*(m+1)] . . . [*l*(n)]

In this way there is only one dimension with an irregular selection. Furthermore, with this choice the matrix does not change the number of dimensions upon lvalue conversion.

Example:

**float** A[2][3][4][5][6];

**int** I[][3]={{0,1,3}, {1,2,0}, {1,2,3}, {0,1,1}};

A[I]; // A matrix of type **float**[24][5][6] with selection [{7,20,23,5}[:]]

That is, if we use **Α** to represent the object at A accessed with type **float**[24][5][6], the selection is {**A**[7], **A**[20], **A**[23], **A**[5]}.

In all the above, if A carries a selection and this is *k*-dimensional, instead of the type of A the type of A[0] . . . [0] has to be taken, where there are *k* [0]’s.

With this choice **\_Lengthof** gives the number of elements selected in the matrix.

Short interpretation

In this case, the type before lvalue conversion is always the same as after lvalue conversion, except for the brokenness qualifier. Taking the same example as above, the type of A[I] is **float**[4][5][6].

### As left operand in an assignment

An array with an indexed selection can be used as the left operand of an assignment provided the selection has no duplicate elements. This embraces a stepped selection with a step equal to zero as a particular case.

### Singleton or not

If the matrix A has *n* dimensions and the depth of the selection is *m*, the selection has *n*-*m*+1 dimensions. If therefore *m* equals *n*, the selection is a 1-dimensional array:

**int** A[5][6], I[][2]={{0,1}, {1,2}};

A[I]; // {A[0][1], A[1,2]}

If in addition the index matrix has one element we get a one-dimensional array with one element:

**int** J[][2]={{0,1}};

A[J]; // {A[0][1]}

A[I[0:1]]; // {A[0][1]}

Since obviously *n* is the maximum possible value for *m*, there is no way to obtain a single-ton from an indexed selection, even after lvalue conversion.

Indeed, there is no way to obtain a singleton from any selection whatsoever. Array subscripting is needed.

### Margins

Long interpretation

We have not yet fully specified the type of a selection like A[I] above before lvalue conversion. We have said that it is a matrix of type **float**[24][5][6] with selection 7,20,23,5, but not what the resulting type is. It can be **float**[24][5][6], but it can also be **float**[19][5][6], where the number 19 comes from 23-(5-1), and A[I] goes from **A**[5] to **A**[23].

if we have chosen stepped selections, no matter how complicated they be, to be restricted to the interval of selected elements, it seams we should do the same for indexed selections. To exhibit a plausible example,

**float** A[6][10];

**int** I[][2]={{*a*,*b*}1, {*a*,*b*}2, ... {*a*,*b*}*l*};

A[I]; // Has type **float**[max{*ai*\*10 + *bi*} - min{*ai*\*10 + *bi*} + 1], 1 ≤ *i* ≤ *l*.

and has no margins.

### Direct selection

When using indexed selections with a fixed number of elements in the selection, having to express it through an intermediate index matrix seems an unnecessary roundabout. Instead of having to write

**int** I[3]={0,2,n}; A[I];

*or* A[(**int**[3]){0,2,n}];

simply write A[{0,2,n}[:]] or, more simply, A[0,2,n]. We do not propose the former to be allowed, just the latter. This latter syntax production clashes with array subscripting, because the subscript in this construct can be “comma expression”, not just an assignment expression (which itself seems too much). We ignore this for the moment and consider it at the end of this section.

The interpretation of the list is that if its elements are singletons they represent the elements selected from the outermost dimension, while if they are themselves brace enclosed lists then each of these lists represents a multidimensional selection, and obviously all the lists must have the same number of elements:

**float** A[4][4];

A[0,2,n]; // {A[0], A[2], A[n]}

A[{0},{2},{n}]; // {A[0], A[2], A[n]}

A[{0,0},{0,2}] // {A[0][0], A[0][2]}

A[0,2] // {A[0], A[2]}

A[{0,2}] // {A[0][2]}

A selection like A[{0,2}] is not ambiguous because it cannot mean {A[0], A[2]}, which needs [0,2]. Nor it can be A[0][2], for reasons already explained.

A direct selection is the same as a selection with an array as the index, composed of the elements of the given list. So, just as with indexed selections, the number of elements within [] is the number of elements of the selection.

The values of the **\_\_STDC\_ARRSEL\_** macros should have the same meaning for braced selections than for indexed selections given by a compound literal.

We do not allow side effects in the expressions composing the list. Restricting them to an integer constant expression or an identifier seems too much, since one may write A[0,1,2, n,n+1,n+2], for example. We do impose (that is, if we did provide wording) that their values have to be nonnegative.

### Constant range expressions

The recently introduced *constant range expression* (CRE) is another natural way of specifying a selection, and it can be combined with a comma-separated list of integers:

A[0, 3...10, 13]

Constant range expressions duplicate the functionality of range selections of the form B:L with B and L integer constant expressions. This is a reason strong enough to exclude them *if they were not already in the language*. Since they are, the obvious choice is to exclude range selections of the kind B:L, extending range expressions to include non-constant ones. But we have already argued that the specification *beginning* : *end* (or *beginning* ... *end,* the argument is not about the syntax) is a bad choice for C. The type of the resulting expression (after lvalue conversion at any rate) depends on the value of the length *l*, and in particular it should be given by an integer constant expression when it is a compile-time constant, as in [2\*n:4], which in the *beginning* : *end* form would become [2\*n:2\*n+4]. This explicit presence of the constant length is desirable not only in form but even more in substance for the generated program, to make it possible for the compiler to translate the expressions of which they are part into vectorial instructions.

#### Constant or not

CRE are, as their name implies, given by integer constant expressions. We like to keep it this way for array selection from a matrix. For any selection which is not constant the present proposal gives the programmer plenty of tools for expressing it; CRE are just another syntax for selections [B:L] with constant B and L. On the other side, we think the comma-separated integers need not be constant, for if A[(**int**[2]){n,n+2}[:]] is allowed it seems difficult to justify that A[n,n+2] is not.

### The different kinds of array selections

#### Terminology

*Empty selector:* []

*Range selector:* [B:L], [b...e], [B:L:s], [:], [::]

*Indexed selector:* [I] (I may or may not carry a selection)

*Direct selector:* [K’, K’’, ... ,K(l)], [{k(1), ... ,k(m)}’, {k(1), ... ,k(m)}’’, ... ]

Here B, L, s, k stand for expressions of interger type, b, e for integer constant expressions, I for an expression of array type one- or two- dimensional and K for either an expression of integer type or a CRE.

Note that we have included a single CRE in range selectors.

#### The most general selection carried

As a result of the combination of all possible range selections, an array carrying a nonempty selection will always carry a certain selection in each dimension, for a number *m* of dimensions starting from the outermost one. In each dimension the kind of selection is one of \*, *b*:*l*, *b*:*l*:*s* or *irregular*, where \* means “all elements are selected” and an irregular selection is given by the index array or direct selection used for it, in which case the length of the dimension it applies to is the product of the lengths of the dimensions involved in the array.

### The fature test macros for indexed and direct selections

**\_\_STDC\_ARRAY\_SELECTIONS\_\_**: The words “range selections” which refer to what is supported, have to be replaced by “array selections beyond empty selections”.

**\_\_STDC\_​ARRSEL\_​STEPPED\_\_**: If indexed selections are allowed, stepped selections have to be allowed too, including with a step equal to zero, for it is just a particular case of indexed selection; i.e., a stepped selection can be achieved by means of an indexed selection, though if the length of the former is not an integer constant expression a variable length array may be needed for the index matrix (if we know a bound of the said length, for instance if the matrix on which the selection is performed is not a top level VLA and the step is not zero, a fixed length array sliced to a variable length can be used as the index).

Therefore, there are two possibilites for this macro with regard to indexed selections: That a value 1 implies that both stepped and indexed selections are supported, or that a value 1 implies only support for stepped selections and support for indexed selections is communicated by a value of 2 here. We prefer the second one, which splits support for indexed selections from support for range selections.

Direct selections require the translator to place the indices in the translated program. this is different from indexed selections, where the compiler need only replace A[*i*] by A[I[*i*]], where A and I are the addresses of the array denoted by the expressions A and I respectively. But placing a list of values in the code, or a list of expressions to compute certain values, is already done for initializers. Since, from the user viewpoint, indexed and array selections are very similar, we prefer to keep them together in the feature test macros. Therefore, support for direct selections is included together with support for indexed selections when **\_\_STDC\_​ARRSEL\_​STEPPED\_\_** is 2.

**\_\_STDC\_ARRSEL\_​NESTED\_\_**: A value of 0 here does *not* mean that array or direct selections can only be one-dimensional. The added complexity of two- or higher- dimensional range selections is that a broken second (or inner) dimension can arrise. Hence, the address of A[0][0] might not be the same as that of A[0]; also, A[0] will not be a “plain” array. As constrast, a selection {*e*,*f*} collapses the first two dimensions of A into one and selectes there the element *e*·*l*+*f*, where *l* is the length of A; this is the element at offset *e*\**s*+*f*\**s*’ from the base of A, where *s* is the size of each (array) element of A and *s*’ that of A[0]’s elements. These computations of offsets are right provided A is not carrying a broken selection, and in particular if it is not carrying a selection, which is precisely what **\_\_STDC\_​ARRSEL\_​​NESTED\_\_** guarantees.

Nor is there a need for two indices when translating range operations:

*T* A[n]; **int** I[n]; *T* A[n][l]; **int** I[n][2];

A[I[:]] = B[:]+C[:]; A[I[:]] = B[:]+C[:];

for *i* = 1..*n* A[*e*(*i*)]=B[*i*]+C[*i*] for *i* = 1..*n* **A**[*e*(i)\**l*+*f*(i)]=B[*i*]+C[*i*]

where *e*(*i*) at the left stands for the *i*-th element of I and *e*, *f*, *l* at the right have the same meanings as above, and **A** there stands for the matrix at the address of A interpreted with type *T* A[*n*\**l*].

What a value of 0 in this macro would mean is that indexed and direct selections can only be applied to the same expressions as a [B:L] selection; i.e., expressions of pointer type or arrays not carrying a selection or carrying an empty selection.

**\_\_STDC\_ARRSEL\_​CONSTANT\_\_**: If it is 1, only **constexpr** arrays are allowed as the indices, or compound literals where all the elements are integer constant expressions, or strings. For direct selections, it restricts the integers therein to ICE.

Some intermediate combinations could be possible, such as requiring a fixed length array as the index. But as we argued, it is better to restrict the possible combinations of partial implementations. Note that a value of 1 in this macro also implies that the length of the selection carried by the index matrix, if it carries one, is given by an integer constant expression.

### Comma-separated list

#### Mixing with CRE

It may be preferred to keep a comma-separated lists of integers and constant range expressions separated, so that

A[3,6,5,2,1], A[3...10]

would be allowed but A[0, 3...10, 13] not. Since a CRE could always be expressed by a (possibly long) comma-separated list of integers we prefer to allow the mixing; that is, a CRE in the middle of a list is not different than many single values in its place.

However, a translator can treat a lone CRE as the equivalent [B:L] selection, and may place the values of a comma-separated list with no CREs in the generated code (or just reserve the space for those that need to be computed at runtime) and use that in-memroy list to take the indices from there at runtime. This second strategy will fail or become inadequate if a range expression specifying a long range is inserted in the list:

A[0,1, 0...99'999, 99'998,99'999]

A long list may also arise as the result of a use of **#embed**. In order that the implementation can store all the integers in memory, we allow it to place a limit on their number:

— 32767 for the total number of bytes required to store the subscripts specified in a direct array selector list (in a hosted environment only), counting each number in a constant range expression individually.

which copies the limit for the total number of bytes in an object. We’d like to see a similar but substantially smaller limit for freestanding environments, but since there is none currently expressed for the number of bytes in an object, we don’t express one here either.

Whether the numbers within each {} in case of bidimensionla lists, equal in number to the number of dimensions in which the selection acts, have to be stored individually or it is possible to just store the resulting index in the collapsed matrix, depends on whether all quantities invovled are integer constant expressions or not: those numbers and the sizes of the arrays by which they have to be multiplied. These bidimensinoal lists cannot contain CREs, so we don’t think any program will be restricted on that side.

An implemantation may be able to handle lists mixing constant range expressions and individual values without having to store all the values in the range expression, but is not required to.

#### Conflict with array subscripting

We have designed the syntax of comma-separated lists as selectors as we would like it to be. But there is an obvious problem: the expression in a subscript selection may be include the comma operator. That is, currently A[3, 0, 1, 5] is interpreted as A[5]. There are several solution for this.

1. To add an extra pair of {} enclosing the whole list. This is the most obvious and straightforward solution.

We did like this when preparing this document. This proved cumbersome, specially for multidimensional selections, as in A[{{1,2},​{2,3},​{3,3}}]. Mandating them just for one-dimension selections is not possible for then a selection like A[{1,2}] becomes ambiguous. It also goes against common practice everywhere that a comma-separated list enclosed in some brackets represents a list of selected elements (the list is already enclosed by the [] brackets).

1. To let , inside the [] operator be interpreted like the comma operator or like the comma of a direct selection list according to some pragma or other directive specifying the version of the language, as has been proposed.

We think the definition of such a directive would be very problematic. What if an identifier is declared in “new” mode using some new feature and then used in the “old” mode, for example? However, a directive that changes the way the program is translated *only for selected features* is easy. For example

 **#pragma** STDC FEATURES 29

If the value is < 29 the comma is interpreted as the comma operator and direct selections other than a CRE are not allowed; otherwise, the expression *k* in [*k*] for the subscripting operator is a conditional expression. this way old files can be compiled with FEATURES set to some value < 29 and new code with it set to 29.

In addition it can change the way I is treated, or if 0[*p*] is allowed, for example.

This pragma would have an implementation predefined value ≤ 29 (that compilers would control via an invocation flag)

1. A pragma specific for this situation. For example,

**#pragma** STDC ARRAY\_COMMA 0

1. Use the **\_\_STDC\_ARRAY\_SELECTIONS\_\_** macro. If it is defined and defined to 1, the comma stands for list separator.

Our preferred solutions are the second and the fourth ones. We don’t want the first one. The fourth solution has the drawback compared with the two previous ones that the state cannot be changed within the translation unit. The introduction of the pragma from solution 2 exceeds the scope of this proposal, which is already quite wide. We took solution 4 (that is, this is our preferred choice).

Since an implementation supporting direct selections must also support stepped selections, we could have taken the value of the macro **\_\_STDC\_ARRSEL\_STEPPED\_\_** as the watershed. But the purpose is not to push comma operators inside array subscripting as far as possible, but rather the opposite. That if somebody wants to use array selectors cannot place a comma operator inside an array subscript seems a mild requisite and even desirable.

A comma operator only makes sense if the first operand has side effects, which are not allowed in direct array selectors. Hence, compilation with **\_\_STDC\_ARRAY\_SELECTIONS\_\_** defined to 1 will make those expressions trigger an error. The safest path towards the elimination of those expressions is as follows: first, the code is compiled without array selections (using any version of C older than C2y or using C2y with a switch to turn array selections off) and asking the compiler to issue a warning for discarded expressions with no effect. This will detect dummy comma operators. These are likely to be bugs in the code. These are fixed. Then the code is compiled with array selections. Comma expressions within [] with side effects will cause a compilation error. For these, the subscript is enclosed in (). E.g., [(p++,n)].

## Our final choice for the type

As can be seen in the forgoing pages, the short interpretation always gives simpler semantics, but has the problem of the very different memory layout of an array with selection as compared to the corresponding array without selection. On the long interpretation, on the contraty, the memory layout is the same, which hints at that being the right type; the difference being only that some elements are selected, other not. But that is not true, as shown by the next section. For this and other reasons also exposed here below, we finally chose the short interpretation.

### Ignored elements are not padding

In the long interpretation, ignored (not selected) elements seemingly act as padding when the array si operated:

**float** A[10];

A[0:4:3]=2;

{s, *i*, *i*, s, *i*, *i*, s, *i*, *i*, s}

Only selected elements are operated, ignored elements are not.

But there is a difference: padding bytes need not be copied onto; ignored elements *must not* be copied onto. In doing so, elements from the full array would be modified which cannot be modified. Thus, those ignored elements act as bytes outside the operated object, whose modification would change some other object.

The consideration of the ignored elements as *ignored;* i.e., belongin to the array but omitted from the operation about to take place, can still be kept notwithstanding the prevoius analysis. But we prefer to consider those bytes as being outside the object.

### Selection from an array of pointers

As in

**int** \*B[10];

B[2:4]; //Array of four pointers

B[2:4][0:3]; //[a,b,c] [a’,b’,c’] [a’’,b’’,c’’] [a’’’,b’’’,c’’’]

The last object is impossible to accomodate in the long interpretation; it cannot be given a type. The extension needed to give a type to that expression is precisely the short iterpretation: it is an array of four elements, eventhough they may be stored appart from one another in memory.

### Broken vs. potentially broken

Having chosen the short interpretation, broken arrays must be given a different type than plain arrays, since the memory layout is different, and, e.g., memcpy will not copy one onto the other. That difference is taken into account by a qualifier: *broken*. That qualifier is not introduced in the type system: no identifier can be declared with that type, no pointer to an object of that type can be formed and broken objects; i.e., expressions having as type a broken array (which are necessarily lvalues) are not allowed in **typeof**. Since, further, qualifiers are discarded upon lvalue conversion, omiting the mention that these arrays are broken would not change nothing in the semantics of any expression. The term is introduced to keep the type system consistent.

Now, should any array with selection, or any one with a >1-dimensional selection or a [B:L:s] selection where s is not an ICE with value 1 be called “broken”, or only those actually broken? In the long interpretaion it was clear that the term could only apply to those actually broken, since that is the meaning it conveys in that interpretation (for there it is not a qualifier); e.g., only unbroken arrays are allowed in sizeof, in that interpretation.

In the short interpretation the situation is different. Consider the expressions

A[0:8:s];

A[:][0:l];

These expressions are broken arrays or not according to the runtime value of s and l respectively. Attaching the qualifier only to those actually broken would mean that the type of an expression cannot be determined during translation. But the qualifier has not been introduced in the type system, as explained above, and an implementation can ignore it completely, as if it didn’t exist. A translator need only keep track of the selection carried by an array, irrespective of how the standard chooses to call it. The only place it could be noticeable is as operand to **typeof**, and there arrays with nonempty selections are not allowed, whether broken or not. For these we prefer to phrase the text in a way that only actually broken arrays or, more precisely, arrays whose layout is not the same as that of a plain array, are deemed broken.

## Further extensions

### The extensions treated in this section arrise naturally. There inclusion here does not mean that the authors are in favour of their eventual adoption.

### A[B:-L]

One may expect implementations to allow a negative L in A[B:L], write it A[B:-L], as a synonym of A[B:L:-1]. If so, this could be incorporated to the standard in the future.

### Range selection constraint related recommended practice

**Constraints**

**Recommended practice**

For the form [B:L:s] in case the postfix expression is a complete array which is not a variable length array, L is an integer constant expression and s is not, implementations are encouraged to produce a diagnostic message in case L is greater than the length of the array or, if also B is an integer constant expression, both B+L and B-L fall outside the range of valid indices for the array. These expressions can only have defined behavior if s evaluates to zero.

The rationale for this is that a step which is not an integer constant expression likely takes different values on different evaluations. Also, that a range selection which can only be valid if *s* is zero should be written with a literal 0 in place of s, or at most an i.c.e with value 0.

### Relaxing the UB of overlapping in assignments

4 If the left operand of an assignment expression is an array, for each singleton *i* of it in which a value is stored let C(*i*) be the set of singletons that need to be read, in the expression at the left of the assignment operator, in order to compute the value to store in *i*. If C(*i*) includes another singleton of the array which also has a value stored in it by the assignment, the behavior is undefined. (Option 1) the object representation of *i* becomes unspecified.

Or even more relaxed:

(Option 2) ... another singleton *j* ... the object representation read for *j* for the computation of *i* is unspecified.

The latter is more relaxed as shown by the following examples:

**EXAMPLE**

**unsigned char** A[10];

A[0:9] = 3 + 0\*A[1:9]; //A[0:9] becomes unspecified in option 1. But in

 //option 2 the unspecified values read from A[1:8]

 //are irrelevant for result of the operation.

After the following expression

A[0:9] += A[1:9];

all values in the range A[0:8] become unspecified while A[8] is well defined, in both options. Also, after

A[2] = A[1] = A[0] = 1;

A[0:2] = A[1:2];

the value of A[0] becomes unspecified, for while the expression does not modify A[1] a value is stored in it. A[0] equals 1 in both options.

**EXAMPLE** The unspecified value read for *j* may lead to undefined behavior:

**int** A[3]:

A[0]=0; A[1]=1; A[2]=2;

A[0:2] /= A[1:2];

Here, in option 2, the value read for A[1] for the computation A[0]/A[1] is unspecified, and if it is zero the behavior is undefined. Option 1 here is more restricted towards the possible outcome: A[0] becomes unspecified but the program does not have undefined behavior.

We prefer option 1, which does not force the translator to compute a correct value when overlapping occurs in cases like A[0:9] = 3 + 0\*A[1:9] above. But the last example shows that, if option 1 is chosen, lee in the reading of *j* is also needed, so as not to force a defined behavior (though resulting in an unspecified value) when, e. g., division by zero may occur. Considering this, the text we propose combines the freedom given to the compiler of both options (i.e., is the strictest for the programmer):

the object representation read for *j* for the computation of *i* is unspecified and the object representation of *i* becomes unspecified.

We like this constraint in the possible behaviour of the program, with respect to the current undefined behavior of this proposal, for it removes an unnecessary u. b., limiting it to an unspecified value in most cases, which is what the emitted instructions could possibly do. It may be that an allowance for unspecified representation of all the computed elements, not just those involved in the overlapping, is necessary. Implementation experience will tell.

### Relaxing the restriction for overlapping

The restriction for overlapping can be partly lifted, if it be so desired, to allow either or both of

A[0:9] = 2\*A[3];

A[0:9] = f(A);

### A[B:L][B’:L’] when the elements of A[B:L] are pointers

In a selection of the form A[B:L] where A is not an array with selection the resulting object is the same whether A has array or pointer type, both in its memory layout and in its type:

**int** A[10], \*B;

A[2:5]; B[2:5]; //Both are an array of 5 **int**.

But if A is itself an array with selection the situation is different:

**int** A[10][6], \*B[10];

A[2:4][0:3]; //[a,b,c,*i,i,i*, a’,b’,c’,*i,i,i,* a’’,b’’,c’’,*i,i,i,* a’’’,b’’’,c’’’,*i,i,i*]

B[2:4]; //Array of four pointers

B[2:4][0:3]; //[a,b,c] [a’,b’,c’] [a’’,b’’,c’’] [a’’’,b’’’,c’’’]

Here *i* represents an ignored (not selected) element. In the last line we’ve got four arrays, at the addresses pointed to by B[2], B[3], B[4] and B[5]. The memory layout is very different form A[2:4][0:3] and the four arrays may not even lie in the same storage instance.

Allowing constructions like the latter might add a substantial burden to implementers. It seems these would have few use cases. It may on the other hand seem useful. Actually, both perceptions are not contradictory. We think it is better to have implementations first implement multidimensional selections just on multidimensional arrays, then allow or not this further extension based on their feedback.

Long interpretation

The definition of a type for this kind of selection before lvalue conversion is difficult. We may say it is an “array with selection of sparse type”. Then make the type of any instance of this incompatible with any other type, including other sparse selections, and insert appropriate wording for the assignment and ++, -- operators. Obviously, these cannot be operands to **sizeof** and should not be to **typeof**.

Short interpetation

The type and value returned by **sizeof** are the same as for any other broken array.

### typeof, sizeof, \_Unselect() and \_Value()

Long interpretation

The restrictions which apply to arrays with selection in **typeof** and **sizeof** have been justified. We’d rather add **\_Unselect()** and **\_Value()** operators than lift those restrictions. It must be clear whether the user wants the type / size of the whole matrix or just that of the selection:

**int** A[10][10], B[20], n;

**typeof**(**\_Unselect**(A[2:3][0:5])) // Clear. **typeof**(A[2:3]). **int**[3][10]

**typeof**(**\_Value**(A[2:3][0:5])) // Clear. **typeof**(**int**[3][5])

**typeof**(A[2:3][0:5]) // ?

**typeof**(**\_Unselect**(B[2:n:4])) // **typeof**(B[2:1+4\*(n-1)]). **int**[4*n*-3]

**typeof**(**\_Value**(B[2:n:4])) // **typeof**(**int**[4])

**typeof**(B[2:n:4]) // ?

**\_Unselect()** makes visible whether margins are retained or not:

**typeof**(**\_Unselect**(A[2:3][0:5][0])) // **int**[10], if margins are kept.

**typeof**(**\_Unselect**(A[2:3][0:5][0])) // **int**[5], if margins are not kept.

When used for reselecting, recovering all the elements of the full array is probably not a good choice:

**#define** invert3(x) **\_Unselect**(x)[0:3] = 1/**\_Unselect**(x)[0:3]

The macro probably does not work as intended for broken arrays. It does not select the first three elements from x, but the first three of the corresponding full array

Short interpretation

**sizeof** is unambiguous, as is **typeof\_unqual**. **typeof** should return the qualified type in the event that the selected qualifier is added to the language, and in the meantime (forever?) arrays with selections are not allowed there. Therefore, **\_Value()** is of no use for these operands.

**\_Unselect()** cannot be applied to a broken lvalue in the short interpretation, because the memory layout of the array is different than that what the result of **\_Unselect()** should be:

**#define** invert3(x) **\_Unselect**(x)[0:3] = 1/**\_Unselect**(x)[0:3]

The second **\_Unselect()** could be fixed by preceding it with **\_Value()**: **\_Unselect**​(**\_Value**(x)), but that is not possible for the first one.

The solution is to split the property of carrying a selection from the brokenness qualifier. Thus, **\_Unselect()** applied to an lvalue would remove the selection but the resulting arrays would still be broken-qualified if it was so.

### Functions taking and returning arrays

Now that there is a way of preventing a matrix to decay to a pointer, functions may be declared to take arrays as argument, as in the following example:

**double** determinant3(**double** A[:3][3]){

 **double** d;

 /\* ... \*/

 **return** d;

}

**double** M[3][3], N[6][6];

determinant3(M[]);

determinant3(N[0:3:2][0:3:2]);

The obvious choice for the parameter and, we would say, the right choice, is **double** A[3][3], which we all know is not possible.

As for the returned value, now arrays make sense because they can be assigned to:

**typedef double** dbl33[3][3];

dbl33 invert3(**double** A[:3][3]){

 /\* Compute A-1 and store it in A \*/

 **return** A;

}

**double** M[3][3], N[3][3];

N= invert3(M[]);

The declaration can be written without the need of a **typeof** following the rule that a declaration mimics the use:

**double** invert3(**double** A[:3][3]) [3][3];

We would like the parameter also to be delcared by means of the defined type:

dbl33 invert3(dbl33 A);

but as we noted this is not possible.

### Functions acting as range operators

Suppose we want to compute the square root of all the elements on the main diagonal of a matrix. Writing

sqrt(N[0:n:n+1])

obviously doesn’t work. What is needed is a way of saying that the function has to act on each of the selected values. We thought of the following syntax for it:

sqrt[](N[0:n:n+1])

The semantics is that [] after the function name means that there are as many invocations of the function as there are selected elements in its arguments which are arrays with selection (the selections in the different arguments must match). All other arguments get evaluated once. Examples with more than one argument:

atan2[](Y[0:n],X[0:n])

atan2[](A[1][0:n],2.5)

The result is an array with selection; that is, the expression has array type and carries a selection. The selection is of the form of that of the arguments after lvalue conversion, which must be identical for all of them, and the type of the singletons that of the return value of the function. This array can be used anywhere an array with selection can:

Y[:] = log[](tan[](0.5\*F[:]))

Σ[:] = sqrt[](N[0:n:n+1])

A[::] = exp[](Ω[::])

There is no concurrence with the use of the [] operator as empty selector, since the identifier used to call a function may be a function pointer but not an array of function pointers. For such an identifier as the latter [] retains it normal meaning, and a list of arguments cannot follow.

## Further editorial fixes

### 6.5.16 Conditional operator

The paragraph on the determination of the common type when both operands are pointers or **nullptr\_t** or a null pointer constant (p. 6 currently, p. 9 in our proposal) is too convoluted as a result, we presume, of incremental editing, as it often happens in the standard. We have simplified it. No semantic change is intended.

### 6.5.17 Assignment operators

The paragraph restricting the overlapping of the asignee with the read object had to be modified to make it apply only to singletons, and this required some minor adjustments to the sentence. We have modified it further so as no to speak of the type of an object, but of the expression used to access it. There is a proviso near the beginning of the standard to make “the type of an object” mean that of the identifier used to access it, but since here we are referring to an object referred to by two identifiers (the one at the left of the assignment and the one at the right), it seems that a direct mention of the type of the identifiers is clearer:

If the left operand is not an array and the value being stored in it is read from another object that overlaps in any way its storage, then the two objects shall occupy exactly the same storage and the type of the expression used to access the object read shall be a qualified or unqualified version of a type compatible to that of the left operand; otherwise, the behavior is undefined.

### 6.5.17 Assignment operators (again)

The paragraph restricting the overlapping of the asignee with the read object is placed under “simple assignments” (it is par. 3), while it applies to any kind of assignment. It is true that compound assignments are described as equivalent to a certain simple assignment, but we feel it would be clearer if the paragraph were “promoted” to assignment operators in general.

Our proposal adjoins one paragraph and several examples to that paragraph 3, and those should be moved together with it if it were moved. We have not done so.

## Wording

Here text is provided for empty and range selections. Blue text is new text, green one is changed text, ~~gray~~ text is to be removed. Dark blue text is new text for the option a zero step is allowed, dark yellow is new text for the option a zero step is not allowed. We noted that we do not consider this latter option.

6.2.5 Types

27 An object or value which is not of array type is called a *singleton*. If the element type of an array is not an array type, the elements of the array are *its singletons*. If the element type is an array type, the singletons of the array are those of its elements.

**6.3.3.1 Lvalues, arrays, and function designators**

1 An *lvalue* is an expression with an array type or a complete object type that potentially designates an object;54) if an lvalue does not designate an object when it is evaluated, the behavior is undefined. When an object is said to have a particular type, the type is specified by the lvalue used to designate the object.

2 A *modifiable lvalue* is an lvalue that either:

— Does not have array type, does not have an incomplete type, does not have a const-qualified type, and if it is a structure or union, does not have any member (including, recursively, any member or element of all contained aggregates or unions) with a const-qualified type; or

— has array type and its singletons are modifiable lvalues

3 Except when it is the operand of the **sizeof** operator, or the typeof operators, the unary & operator, the ++ operator, the -- operator, or the left operand of the . operator or an assignment operator, an lvalue that does not have array type is converted to the value stored in the designated object (and is no longer an lvalue); this is called *lvalue conversion*. If the lvalue has qualified type, the value has the unqualified version of the type of the lvalue; additionally, if the lvalue has atomic type, the value has the non-atomic version of the type of the lvalue; otherwise, the value has the type of the lvalue.

4 An lvalue which is an array with selection undergoes lvalue conversion in the same contexts as singleton lvalues. The result is an array with the same selection and with its singletons having undergone lvalue conversion as described above.

“with its singletons” instead of “with its selected elements” because the selected elements need not be singletons and “described above” is only for singletons.

5 **EXAMPLE**

**int** A[6][4]**;**

**const int** B[10][10];

A[:][:] = B[2:6][0:4];

When the expression B[2:6][0:4] undergoes lvalue conversion the result is an array of type **int**[6][4] where each singleton results from the lvalue conversion of the corresponding singleton in B[2:6][0:4].

6 If an lvalue ~~(that does have array type)~~ designates an object of automatic storage duration that never had its address taken, and that object is uninitialized (not declared with an initializer and no assignment to it has been performed prior to use) when it undergoes lvalue conversion, the behavior is undefined. An address of an object is taken by application of the address operator to an lvalue designating the object, by being an element of an array that was designated by an expression that is converted to a pointer as described below, or by being a member of a structure or union object whose address is taken.

7 Except when it is the operand of the **sizeof** operator, or typeof operators, or the unary & operator or one of the two expressions of an array subscripting operator, or the left operand of and range selection operator, or is a string literal used to initialize an array, an expression that has type “array of *type*” and the array does not carry a selection is converted to an expression with type “pointer to *type*” that points to the initial element of the array object and is not an lvalue. If the array object has register storage class, the behavior is implementation-defined.

8 [...]

**Forward references:** address and indirection operators (6.5.4.3), assignment operators (6.5.17), common definitions <stddef.h> (7.21), initialization (6.7.11), array subscripting (6.5.3.2), range selection (6.5.3.3), postfix increment and decrement operators (6.5.3.6), prefix increment and decrement operators (6.5.4.2), the **sizeof** and **alignof** operators (6.5.4.5), structure and union members (6.5.3.4).

### 6.5 Expressions

6.5.1 General

11 If a subclause allows one operand to be an array with singletons selected, i.e., carrying a selection with as many dimensions as the array has, and does not define explicitly the semantics for that case (this happens for some binary operators), and the operand is such and the other operand is not an array with selection, the operation is performed on each selected singleton according to the semantics described for operands which are singletons. The other operand is evaluated only once. If both operands are arrays with singletons selected, if the number of elements selected from both arrays are not the same the behavior is undefined; if they are the same, the operation is performed on each pair of corresponding selected elements, applying this rule recursively if the element type of any of the two arrays is an array.

12 Whenever an array with a nonempty selection is an operand and the operation is performed on each selected element (whether they be singletons or not), the array *is treated as a range of objects,* and the operation is a *range operation.* Whenever an array is treated as a range of objects the order in which the operations are performed is unspecified.

13 If an operation is a range operation the result of the expression is an array with selection; i.e., the expression is an array with selection. If one operand is an array with selection and the other one is not let *type* be the type resulting from the operation of each selected element with the other operand. If both operands are arrays with selection let *type* be the type resulting from the operation applied to one selected element from each of the arrays. The type of the expression and the selection it carries is the one the array, if there is just one, or the left operand if both of them are arrays with selection, would have after lvalue conversion if the type *T* of its selected elements were replaced by type *type.*

NOTE: The procedure would determine the same type in case the right operand were taken when both operands are arrays with selection, except for assignment operators.

13 **EXAMPLE** 1

**short** A[12], B[12];

**int** C[8][12][4], D[8][10][2], b;

B[0:6] = A[0:6] + A[6:6];

D[:][0:6][:] = C[:][0:6][0:2] + C[:][6:6][0:2];

b = (A[] == B[]);

In the expression A[0:6] + A[6:6] each of the operands is an array of six elements with all its elements selected. The expression is therefore an array of type **int**[6] with all its elements selected and whose values are the sums of the two arrays. The type of the assignment expression of which it is part is also **int**[6]. In the expression C[:][0:6][0:2] + C[:][6:6][0:2], each operand as well as the expression itself and the assignment expression of which it is part are of type **int**[8][6][2] and carry a three-dimensional selection. The operated elements are C[*i*][*j*][*k*] + C[*i*][6+*j*][*k*]. Finally, A[] == B[] is not a range operation.

14 **EXAMPLE** 3

**float** A[n], B[n][n], C[n];

A[:] = B[:][:] \* C[:];

The rule applies to B[:][:] \* C[:], yielding B[*i*][:] \* C[*i*]. Each of these is the multiplication of an array with singletons selected, B[*i*], and a singleton, C[*i*]. The rule therefore applies again; the result of each operation is the array B[*i*][*j*]\*C[*i*], with 0≤*j*≤*n*, where *n* is the value to which n evalutes at the delcaration, and that of the multiplication expression is the *n* × *n* array B[*i*][*j*]\*C[*i*].

15 For a range operation, if none of the individual operations would raise a certain floating-point exception, that exception is not raised. If any of the operations would raise it, it is implementation defined whether the exception is raised or not. The corresponding status flag is set or not accordingly.

6.5.3 Postfix operators

#### 6.5.3.1 General

#### Syntax

 *postfix-expression:*

*primary-expression*

*postfix-expression* **[** *expression* **]**

*postfix-expression* **[****]**

*postfix-expression range-selector*

*postfix-expression* **(** *argument-expression-list*opt**)**

*postfix-expression* **.** *identifier*

*postfix-expression* **->** *identifier*

*postfix-expression* **++**

*postfix-expression* **--**

*compound-literal*

 *argument-expression-list:*

*assignment-expression*

*assignment-expression-list* ***,*** *assignment-expression*

 *range-selector:*

**[ : :**opt **]**

**[** *conditional-expression* **:** *conditional-expression* **]**

**[** *conditional-expression* **:** *conditional-expression* **:** *conditional-expression* **]**

**6.5.3.2 Array subscripting**

*The text of this section is to be that of the (hopefully) eventually approved proposal “Array subscripting without decay”.*

6 **EXAMPLE** 2

**int** x[6];

x[2:3][0]; // Designates the element x[2]

**6.5.3.3 Array selection**

**Description**

1 An empty pair of brackets following a postfix expression is an *empt*y *selector.* A postfix expression followed by an empty selector is an *empty selection*. Its intent is to select the matrix as a whole.

2 A postfix expression followed by a construction of the form [:] or [::] or [B:L] or [B:L:s], where B, L and s are conditional expressions is a *range selection,* which selects some elements from the array. The intent of [:] is to select all elements, that of [B:L] to selects L elements starting from the B-th, that of [B:L:s] to select the elements at positions B, B+s ... B+(L-1)\*s and that of [::] to select all elements from all dimensions. The order in which the expressions B, L and s are evaluated is unspecified.

3 Empty selectors and range selectors are collectively called *array selectors.* Empty selections and range selections are collectively called *array selections*.

**Constraints**

4 If the array selector has the form [], [:] or [::] the postfix expression shall be a complete array; If it has any of the other two forms the postfix expression shall be an array or a pointer to a complete object. The conditional expressions shall have integer type.

5 If the array selector is of the form [::] and the postfix expression is an array selection, the array selector of the latter, and that of its postfix expression if this is an array selection, and so recursively, cannot be [::].

6 In any form of the array selector except [::] and [], if the postfix expression is an array with selection its selected elements shall be of array type.

7 If L is an integer constant expression it shall be greater than zero. If s is an integer constant expression it shall be nonzero.

8 If the postfix expression is of array type, any of the expressions B and B+L in the form [B:L], or B and B+(L-1)\*s in the form [B:L:s], if an integer constant expression, shall not be negative. If further the array is complete and is not a variable length array, the value of those expressions as well as that of L in the form [B:L] if an integer constant expression, shall be less than *l*, where *l* is the length of the array if it does not carry a selection or the length of each innermost selected element if it carries a selection.

**Semantics**

9 In the following paragraphs, let *b, l* and *s* be the result of evaluating B, L and s respectively. *b* shall be nonnegative and *l* shall be greater than zero. No restriction applies in general to *s*; in particular, it may be zero. , and s shall be nonzero.

10 If the expression is of the form A[B:L] or A[B:L:s] and A is a pointer or an array which does not carry a selection, the first form selects the range of *l* elements starting from the *b*-th, the latter counted from zero. In the second form the expression s is called the *step,* as well as the value *s*. It selects the elements A[*b*], A[*b*+*s*] ... A[*b*+*s*\*(*l*-1)] (if *s* is zero it selects A[B] *l* times). The resulting array is said to *carry a selection* or to *have (a range of) elements selected.* If the expression is of the form A[B:L:s] and neither *l* nor *s* are 1, the array is said to carry *a stepped selection*. The elements are considered to be selected in order, where A[*b*] is the first, A[*b*+1] or A[*b*+*s*] the second and A[*b*+*l*-1] or A[*b*+*s*\*(*l*-1)] the last. When two arrays with selection are operated, the elements of one are operated with the elements of the other preserving the order.

11 **EXAMPLE** 1

A[0:3] + B[9:3:-2]; // The result is {A[0]+B[9], A[1]+B[6], A[2]+B[3]}

12 If the expression is of the form A[B:L] or A[B:L:s] and A is a pointer or an array which does not carry a selection, let *type* be the type of A[0]. The expression has type “array of *type*”. It has length *l*. If L is an integer constant expression it is an array of known constant length; otherwise, it is a top-level variable length array. In the second form, let |*s*| be the absolute value of *s*. If 1+(*l*-1)\*|*s*| is different from *l* the array is said to be *broken* and its outermost dimension to be a *broken dimension*.

13 If the expression is of the form A[B:L] or A[B:L:s] and A is an array with a range of elements selected, and the type of the innermost selected elements is *T*, then: If *T* is not an array the behavior is undefined. Otherwise, let A have an *m*-dimensional range of elements selected, of type *T*, and *T* be array of *T’*. The expression is then the same array with an (*m*+1)-dimensional range of elements selected of type *T’*, obtained by selecting from each element *v* in the *m*-dimensional range the subarray *v*[B:L] or *v*[B:L:s], which is as described by the previous paragraph (*v* is not an array with selection). If these subarrays are broken, so is A as well as its elements, and so recursively till the elements *v*.

Here is the restriction that in A[R][R’], A[R] cannot be an array of pointers.

14 An expression of the form A[:] is equivalent to A[0:*l*], where *l* is the length of the array A.

15 An empty selection is of the form A[]. If A is an array with selection the empty selection has no effect. Otherwise A is an array without selection and the expression is the same array with a 0-dimensional range of elements selected, namely the whole array (one element selected), and it is said that the array has, or carries, an *empty selection.* An array with an empty selection is equivalent for all purposes to the array with no selection, except that it cannot be converted to a pointer.

16 If the expression is of the form A[::] and A is an *n*-dimensional array with no selected elements or, if it has selected elements, the innermost ones of these are *n*-dimensional arrays, then: If no array selectors follow the [::], A[::] is equivalent to A[:][:] ... [:], where there are *n* [:] selectors; if A is an array with selection *n* may be zero. If array selectors follow (none can be of the form [::]) and among these the range selectors are *m* in number, A[::] is equivalent to [:][:] ... [:], where there are *n*-*m* [:] selectors; *n-m* may be zero.

17 As a consequence of the rules expressed above, an array carrying an *m*-dimensional selection has all the elements from its first *m* dimensions selected. A broken array behaves as if it had a *brokenness* qualifier. Its memory layout is different from that of the corresponding array without the qualifier. This property is lost upon lvalue conversion. Different broken arrays that have the same type may have different memory layouts*.*

19 **EXAMPLE** 2 Consider the array object defined by the declaration

**int** x[3][5];

x[1:2] is an array of 2 × 5 objects and has type **int**[2][5]; it is a subobject of x and has a one dimensional range of elements selected, each of which is an array of five singletons of type **int**. x[0:1][:] is the same array and has selections from both its dimensions, resulting in a two dimensional range of elements selected, each of which is a singleton of type **int**.

20 **EXAMPLE** 3 After the declarations

**int** n = 3;

**int** x[3][5], y[3][n], z[n];

x[:][0:n] is a broken array. Its type is **int**[3][3] and is a variable length array, though not a top-level variable length array. x[1:n-2] is a variable length array of type **int**[n-2][5]; i.e., **int**[1][5]. y[:] and y[:][0:3] both have type **int**[3][3], but the former is variable length array while the latter is not. z[0:2] has type array of two **int**. z[n-3:1] has type **int**[1] and is not a broken array.

x[0:2][0:n+2] is not a broken array but x[0:2][0:n] is, having its second dimension broken, but not the first. x[:][1:3][0] has type **int**[3], carries a one-dimensional selection and is not broken.

21 **EXAMPLE** 4

**int** x[3][5], y[6][20];

x[:][0:2] + y[3:3][k:2:-4]; **//** k is of integer type

Here x[:][0:2] and y[3:3][k:2:-4] are broken arrays of type **int**[3][2]. As operands of the + operator they undergo lvalue conversion and are no longer broken.

22 **EXAMPLE** 5

**int** x[3][3], y[3];

x[0:1] == y[];

x[0:1] has type **int**[1][3] and has one element selected of type **int**[3], which is also the type of y[]. The former could also have been written x[0][], which has type **int**[3] with one element selected of type **int**[3].

23 **EXAMPLE** 6

**int** A[6][6][6];

A[::]; //Equivalent to A[:][:][:]

A[::][0:3]; //Equivalent to A[:][:][0:3]

A[::][0:3][:]; //Equivalent to A[:][0:3][:]

A[::][]; //Equivalent to A[:][:][:]

**6.5.3.6 Postfix increment and decrement operators**

**Constraints**

1 The operand of the postfix increment or decrement operator shall have atomic, qualified or unqualified arithmetic or pointer type, or be an array with elements selected, with the innermost selected elements of any of those types, and shall be a modifiable lvalue.

**Semantics**

2 If the left operand is an array with selection it shall not carry a stepped selection where the step is zero, nor shall its selected elements and so recursively.

3 If the operand is not an array with selection the *operated element*s is the operand. Otherwise, it refers to each of the innermost selected elements.

4 The *adjustment value* is the value used to increment or decrement the value of the operated elements. If the operated elements have pointer type, the adjustment value has type **int** and the value 1; if the operated elements have complex type, the adjustment value has the corresponding real type of the operated elements and the value 1; if the operated elements have decimal floating type, the adjustment value has the same type as the operated elements, 1 as the numerical value, and 0 as the quantum exponent; otherwise, the adjustment value has the same type as the operated elements and the value 1.

5 The result of the postfix ++ operator is the value of the operand. As a side effect the value of the operated elements is incremented by the adjustment value. See the discussions of additive operators and compound assignment for information on constraints, types, and conversions and the effects of operations on pointers. The value computation of the result for each operated element is sequenced before the side effect of updating the stored value of the said element. Both operations are indeterminately sequenced with respect to the same operations on other operated elements. With respect to an indeterminately sequenced function call, the operation of postfix ++ is a single evaluation. Postfix ++ on an object with atomic type is a read-modify-write operation on each operated element with **memory\_order\_seq\_cst** memory semantics.

6 The postfix -- operator is analogous to the postfix ++ operator, except that the value of the operated elements is decremented by the adjustment value.

6.5.4 Unary operators

**6.5.4.2 Prefix increment and decrement operators**

**Constraints**

1 The operand of the prefix increment or decrement operator shall have atomic, qualified or unqualified arithmetic or pointer type, or be an array with elements selected, with the innermost selected elements of any of those types, and shall be a modifiable lvalue.

**Semantics**

2 If the left operand is an array with selection it shall not carry a stepped selection where the step is zero, nor shall its selected elements and so recursively.

3 The value of the operated elements (6.5.3.5) of the prefix ++ operator is incremented. The result is the new value of the operand after incrementation. The expression ++E is equivalent to (E+=1), where the value 1 is the adjustment value (6.5.3.5). See the discussions of additive operators and compound assignment for information on constraints, types, side effects, and conversions and the effects of operations on pointers.

[...]

**6.5.4.3 Address and indirection operators**

**Constraints**

1 The operand of the unary & operator shall be either a function designator, the result of an array subscripting operator or a unary \* operator, or an lvalue that designates an object that is not a bit-field nor an array carrying a nonempty selection and is not declared with the **register** storage-class specifier.

[...]

**6.5.4.4 Unary arithmetic operators**

**Constraints**

1 If the operand is not an array with selection then: The operand of the unary + or - operator shall have arithmetic type; of the ~ operator, integer type; of the ! operator, scalar type. If the operand is an array with selection, the innermost selected elements shall have a type as constrained by the previous sentence.

[...]

5 The result of the logical negation operator ! applied to a singleton is 0 if the value of its operand compares unequal to 0, 1 if the value of its operand compares equal to 0. The result has type **int**. The expression !E is equivalent to (0==E).

**6.5.4.5 The sizeof, alignof and \_Lengthof operators**

**Semantics**

4 When **sizeof** is applied to an operand that has type **char**, **unsigned char**, or **signed char**, (or a qualified version thereof) the result is 1. When applied to an operand that has array type, the result ~~is the total number of bytes in the array~~ equal the number of elements times the size of its elements.101) When applied to an operand that has structure or union type, the result is the total number of bytes in such an object, including internal and trailing padding.

[...]

8 EXAMPLE 2 The following equallity always holds for arrays:

**sizeof**(array) = **\_Lengthof**(array)\***sizeof**(array[0])

6.5.5 Cast operators

**Constraints**

2 One of the following shall hold:

— The type name specifies a void type; or

— the type name specifies an atomic, qualified, or unqualified scalar type and the operand has scalar type or is an array with no selection or carrying a selection of singletons.

— the operand is an array with an empty selection and the type name specifies an array type with the type of the singletons as an atomic, qualified or unqualified version of a type compatible to that of the operand’s singletons.

3 If its operand is an array of fixed constant total length carrying an empty selection and the type name specifies an array of fixed constant total length, the total length of the latter shall be less than or equal to the total length of the operand.

Length and not size, though since the singletons’ types are compatible, there is no difference. Each element from the result comes from one element from the operand.

[...]

**Semantics**

[...]

6 Preceding an expression by a parenthesized type name converts the value of the expression to the unqualified, non-atomic version of the named type. This construction is called a *cast*.102) If the operand is an array which does not carry a selection, it is first converted to a pointer and the cast applies to this pointer. If the operand is an array carrying a selection of singletons the conversion is applied to each of its singletons. A cast that specifies no conversion has no effect on the type or value of an expression.

7 If the operand is an array with selection then: if the type name specifies an array type, the total length of this type shall be less than or equal to the total length of the operand and the value of the expression is an array with an empty selection; otherwise the array carries a selection of singletons and the result is an array with the same dimensions and selection as its operand and with the type of its singletons the one resulting from the cast applied to a singleton.

[...]

6.5.6 Multiplicative operators

[...]

**Constraints**

2 Either operand may be an array with selection. The innermost selected elements must satisfy the constraints set forth in the following paragraphs.

3 Each of the operands, if not an array with selection, shall have arithmetic type. The operands of the % operator shall have integer type.

4 If either operand has decimal floating type, the other operand shall not have standard floating type, or complex type.

6.5.7 Additive operators

[...]

**Constraints**

2 Either operand may be an array with selection. If so, the other operand cannot be an array without selection. The innermost selected elements shall be singletons and satisfy the constraints set forth in the following paragraphs for operands which are not arrays.

3 For addition, when the operands are not arrays with selection, either both operands shall have arithmetic type, or one operand shall be an array or a pointer to a complete object type and the other shall have integer type. (Incrementing is equivalent to adding 1.)

4 For subtraction, when the operands are not arrays with selection, one of the following shall hold:

— both operands have arithmetic type;

— both operands are pointers to, or arrays of, qualified or unqualified versions of compatible complete object types; or

— the left operand is an array or a pointer to a complete object type and the right operand has integer type.

(Decrementing is equivalent to subtracting 1.)

5 If either operand has decimal floating type, the other operand shall not have standard floating type, or complex type.

**Semantics**

6 If an operand is an array without selection, the array is first converted to a pointer to its first element, thence operated as specified for pointers. If both operands have arithmetic type, the usual arithmetic conversions are performed on them.

[...]

13 *(Change* “EXAMPLE” *to* “EXAMPLE 1”*)*

[...]

14 **EXAMPLE** 2 The code

**struct** stra A[10];

A[:] + 1;

has undefined behavior. For while A + 1 would be valid, an array with selection is not converted to a pointer, and the selected elements of A[:] are not of a type that could be an operand of the addition operator.

15 **EXAMPLE** 3 The code

**int** A[10][10];

A[:] + 1;

has undefined behavior. For while A[0] + 1 through A[9] + 1 would be valid, the innermost selected elements of A[:] are not singletons.

6.5.8 Bitwise shift operators

[...]

**Constraints**

2 Each of the operands shall have integer type or be an array with selection with the innermost selected elements of integer type.

**Semantics**

3 The integer promotions are performed on each of the operands. The type of the result is that of the promoted left operand. If the value of the right operand, when a singleton, is negative or is greater than or equal to the width of the promoted left operand, the behavior is undefined.

4 When E1 and E2 are singletons, the result E1 << E2 is E1 left-shifted E2 bit positions; vacated bits are filled with zeros. If E1 has an unsigned type, the value of the result is E1× 2E2, wrapped around. If E1 has a signed type and nonnegative value, and E1×2E2 is representable in the result type, then that is the resulting value; otherwise, the behavior is undefined.

5 When E1 and E2 are singletons, the result of E1 >> E2 is E1 right-shifted E2 bit positions. If E1 has an unsigned type or if E1 has a signed type and a nonnegative value, the value of the result is the integral part of the quotient of E1/2E2. If E1 has a signed type and a negative value, the resulting value is implementation-defined.

6.5.9 Relational operators

[...]

**Constraints**

2 Either operand may be an array with selection. If so, the other operand cannot be an array without selection. The innermost selected elements shall be singletons and satisfy the constraints set forth in the following paragraphs for operands which are not arrays.

3 One of the following shall hold when the operands are not arrays with selection:

— both operands have real type; or

— both operands are pointers to, or arrays of, qualified or unqualified versions of compatible object types.

4 If either operand has decimal floating type, the other operand shall not have standard floating type, or complex type.

**Semantics**

5 If an operand is an array without selection, the array is first converted to a pointer to its first element, thence operated as specified for pointers. If both operands have arithmetic type, the usual arithmetic conversions are performed. Positive zeros compare equal to negative zeros.

6.5.10 Equality operators

[...]

**Constraints**

2 If no operand is an array one of the following shall hold:

[...]

3 If one operand is an array without selection the other operand cannot be an array carrying a selection. If either or both operands are arrays not carrying a selection they are converted to pointers to their first elements and it is to these pointers to which the condition in the previous paragraph applies.

4 If either operand has decimal floating type, the other operand shall not have standard floating type, or complex type.

5 If one of the operands is an array carrying a selection, let *T* be the type of its singletons. Either of the following shall hold:

— The other operand is not an array. If the other operand has pointer type or type **nullptr\_t** so is *T*. The type *T* and the other operand satisfy the constraints expressed in the previous paragraphs for the types of the operands.

— Both operands are arrays with selection. They have the same dimensions and carry equal selections. If the singletons of one of the arrays have pointer type or type **nullptr\_t** so have the singletons of the other array. The type *T* and the analogously defined type *T*’ for the other operand satisfy the constraints expressed in the previous paragraphs for the types of the operands.

**Semantics**

6 If an operand is an array without selection, the array is first converted to a pointer to its first element, thence operated as specified for pointers. The == (equal to) and != (not equal to) operators are analogous to the relational operators except for their lower precedence.105) When operating on singletons, each operand yields 1 if the specified relation is true and 0 if it is false, the result has type **int** and exactly one of the relations is true.

7 [...]

8 ~~Otherwise, at least one operand is a pointer.~~ [...]

9 [...]

10 [...]

11 If one operand is an array with selection with the innermost selected elements of array type, or if it is an array with no selection which does not decay to a pointer (this is a selected array from some larger array, the rule here applying when needed as specified by the recursive rule below), and the other operand is not an array, the result is an array with selection unless the selection is empty or there is no selection, in which case it is a singleton. The result has one element in place of each selected array (or of the whole array if it does not carry a selection), which for the == operator has value 1 if all singletons of the said array compare equal to the other operand and value 0 otherwise. For the operator != the values are the opposite.

sel-A *eq* s

12 If one operand is an array carrying a selection where the innermost selected elements are arrays *a*, and the other operand is an array B carrying an empty selection or carrying no selection and not decaying to a pointer (the latter case can only result from the application of the recursive rule), the dimensions of the selected arrays *a* and the array B shall be the same. The result is an array with one element in place of each *a*, which for the == operator has value 1 if all singletons of *a* compare equal to the corresponding singletons of B and value 0 otherwise. For the operator != the values are the opposite.

sel-A *eq* B[]

13 If both operands are arrays carrying a one-dimensional selection of arrays, their lengths shall be equal and the dimensions of the selected elements in both arrays shall be the same. The result has one element in place of each selected array, which for the == operator has value 1 if all singletons of one operand’s selected array compare equal to the corresponding singletons of the corresponding selected array of the other operand, and value 0 otherwise; for the operator != the values are the opposite.

A[:] *eq* B[:]

A[0], B[0] of arr. type.

14 Recursive rule: If both operands are arrays carrying nonempty selections, at least one of the selections is ≥2-dimensional and at least one of the operands does not have singletons selected, the length of the two selections shall be the same. The result is an array with selection of length equal to the length of the operands, where each element is the result of operating the corresponding pair of selected elements from one and the other operand determined by recursive application of this rule or by one of the previous paragraphs (whichever applies).

A[:]...[:] *eq* B...[:]

A...[0][0] or B...[0] of arr. type.

15 **EXAMPLE** 1

**int** A[4][3], B[4][3], C[3];

**int** E[4][3], F[4], G, H[4], I[4], J;

E[:][:] = A[:][:] == B[:][:];

F[:] = A[:] == B[:];

G = A[] == B[];

H[:] = A[:] != 2;

I[:] = B[:] == C[];

J = A[] == 2;

F[0] equals (A[0][0]==B[0][0] && A[0][1]==B[0][1] && A[0][2]==B[0][2]), and similarly for F[1], F[2] and F[3]. G is 1 if all twelve elements of A compare equal to the corresponding elements of B. H[0] equals !(A[0][0]==2 && A[0][1]==2 && A[0][2]​==2), and similarly for H[1], H[2] and H[3]. Each I[*i*] equals (B[*i*][0]==C[0] && B[*i*][1]==C[1] && B[*i*][2]==C[2]). J is 1 if all twelve elements of A are 2.

16 **EXAMPLE** 2

**int** A[5][4][3], B[5][3], C[5][3];

**int** D[5][4], E[5][4];

D[:][:] = A[:][:] != B[:];

E = B[:][:] != C[:]; // Undefined behavior: E[*i*] = (B[*i*][:] != C[*i*])

Each D[*i*] is determined by the recursive rule and equals A[*i*][:] != B[*i*]. These in turn are determined by the rule of paragraph 12, so that D[*i*][*j*] equals !(A[*i*][*j*][0]==B[*i*][0] && A[*i*][*j*][1]==B[*i*][1] && A[*i*][*j*][2]==B[*i*][2]). The expression for E is, in the first place, determined also by the recursive rule, yielding E[*i*] = (B[*i*][:] != C[*i*]). This one has undefined behavior because the operand C[*i*] is an array which does not decay to a pointer and which does not carry a selection and B[*i*][:] is an array carrying a selection of singletons, and there is no rule for that case.

17 **EXAMPLE** 3

**int** A[1], B[1];

**int** C[1];

C[:] = A[:] == B[:];

C[0] = A[] == B[];

The result of the first comparison is an array which is assigned to an array. The result of the second comparison is a singleton which is assigned to a singleton.

6.5.11 Bitwise AND operator

[...]

**Constraints**

2 Each of the operands shall have integer type or be an array with selection with the innermost selected elements of integer type.

6.5.12 Bitwise exclusive OR operator

[...]

**Constraints**

2 Each of the operands shall have integer type or be an array with selection with the innermost selected elements of integer type.

6.5.13 Bitwise inclusive OR operator

[...]

**Constraints**

2 Each of the operands shall have integer type or be an array with selection with the innermost selected elements of integer type.

6.5.16 Conditional operator

[...]

**Constraints**

2 The first operand shall have scalar type.

3 If the second and third operands are singletons one of the following shall hold for them:

[...]

4 If either of the second or third operands is an array without selection it is converted to a pointer to its first elements and it is to these pointers to which the condition in the previous paragraph applies.

5 If either of the second or third operands has decimal floating type, the other operand shall not have standard floating type, or complex type.

6 If either of the second or third operands is an array carrying a selection then so shall be the other. Their dimensions of the arrays and of their selections shall be the same. The singletons of which one and the other array are composed shall satisfy the constraints set above for operands which are not arrays. In addition, if the singletons of one of the arrays have pointer type or type **nullptr\_t**, so shall have the singletons from the other operand.

**Semantics**

7 [...]

8 If the second and third operands have arithmetic type (after conversion to pointer for arrays not carrying a selection), [...].

9 If one operand is a null pointer constant, the result has the type of the other operand. Otherwise, if one operand has type **nullptr\_t**, the result has the type of the other operand. Otherwise, if both the second and third operands are pointers, the result type is a pointer to a type qualified with all the type qualifiers of the types referenced by both operands. If the latter types, unqualified, are compatible, the result is a pointer to the appropriately qualified version of the composite type; otherwise, one of the operands is a pointer to **void** or a qualified version of **void** and the result type is a pointer to the appropriately qualified version of **void**.

10 EXAMPLE [...]

12 If both operands are arrays with selection the common type is determined by applying the above rules to the types of their singletons.

6.5.17 Assignment operators

**6.5.17.1 General**

[...]

**Constraints**

2 An assignment operator shall have a modifiable lvalue as its left operand. If the right operand is an array with selection the left operand shall be an array. If the left operand is an array with an innermost selection of singletons, then the right operand shall be a singleton, or an array without selection or an array carrying an innermost selection of singletons.

[...]

**Semantics**

4 If the left operand is an array with selection it shall not carry a stepped selection where the step is zero, nor shall its selected elements and so recursively.

**6.5.17.2 Simple assignment**

**Constraints**

1 If the left operand is not an array one of the following shall hold:

[...]

2 If the left operand is an array with an innermost selection of singletons, these together with the right operand if not an array with selection or the selected singletons of the right operand if it is an array with selection must satisfy the constraint above for the case the left operand is not an array. Furthermore, if the right operand is an array with selection and singletons of the left operand have pointer type or type **nullptr\_t**, so shall have the singletons of the right operand.

3 If the left operand is an array with selection and the innermost selected elements are of array type, then the right operand shall be an array carrying an empty selection, its dimensions shall be the same as that of the selected arrays of the left operand and the singletons from which the left and right arrays are composed shall satisfy the constraint above for operands which are not arrays. In addition, if these singletons from the left operand have pointer type or type **nullptr\_t**, so shall have the singletons from the right operand.

**Semantics**

4 If the left operand is an array without selection the expression is equivalent to one in which the left operand has had the empty range selection [] applied to it.

[...]

6 If the left operand is not an array and ~~if~~ the value being stored in ~~an object~~it is read from another object that overlaps in any way its storage, then the two objects shall occupy exactly the same storage and the type of the expression used to access the object read shall be a qualified or unqualified version of a type compatible to that of the left operand; otherwise, the behavior is undefined.

7 If the left operand is an array, for each singleton *i* of it in which a value is stored by the assignment let C(*i*) be the set of its singletons that need to be read, in whole or in part, in the expression at the right of the assignment operator in order to compute the value to store in*i*. If C(*i*) includes another singleton of the array which also has a value stored in it by the assignment, the behavior is undefined. If C(*i*) includes *i*, the condition in the previous paragraph applies to it. C(*i*) includes all the values that are read in the abstract machine in the chain of operations expressed by the right operand that determine de value to store in *i,* even if they are not needed from the mathematical viewpoint.

8 EXAMPLE 1 Consider the following assignments

**int** A[6];

A[1:3] = A[1:3] + 0\*A[3];

A[:] = A[:] - A[:];

A[:] = A[3];

In the first assignment C(*i*) is {*i*, A[3]} for each *i* (where A[3] means the abstract element A[3], not the value of the expression A[3]) and the behavior is undefined. In the second assignment C(i) is {*i*} for all *i.* In the third assignment C(*i*) equals {A[3]} for all *i* and the behavior is also undefined, even if the expression does not change the value of A[3].

9 EXAMPLE 2 In the following piece of code

**int** A[9];

**char** B[7];

A[0:3] = A[B[0]:3:-1];

A[3] = ((**char**\*)A)[0:7] == B[];

A[3:3] = ((**char**\*)A)[0:7] == B[];

the first assignment has defined behavior if 4 ≤ B[0] ≤ 8. The second assignment has defined behavior always because the left operand is not an array and the value to store in it is not read from an object, while the third one has undefined behavior if **sizeof**(**int**) ≤ 2.

[...]

13 EXAMPLE 5 Assignments where the left operand is an array.

**int** A[5][4], B[5][4], C[4];

A[:] = C[]; // Equivalent to A[0][:]=C[:], A[1][:]=C[:], etc.

A[:] = B[0][]; // A[0][:]=B[0][:], A[1][:]=B[0][:], etc.

A[:] = B[:]; // Constraint violation

A[:][:] = B[:][:]; // Write this instead

A = B[]; // Equivalent to A[:][:] = B[:][:]

A[0][:] = C; // Implicit conversions from **size\_t** to **int**

Writing C[] and B[0][] above, instead of C or B[0], is necessary to prevent the array decaying to a pointer.

**6.5.17.3 Compound assignment**

**Constraints**

1 For the operators += and -= only, if the left operand is not an array with selection then: either the left operand [...]

2 For the other operators, if the left operand is not an array with selection then: the left operand [...]

3 If either operand has decimal floating type, the other operand shall not have standard floating type, or complex type.

4 If either operand is an array with selection, the innermost selected elements shall be singletons and shall satisfy the constraints set forth in the previous paragraphs.

**6.7.3.6 typeof specifiers**

**Constraints**

3 The typeof operators shall not be applied to an expression that designates a bit-field member.

4 The **typeof** operator shall not be applied to an array carrying a nonempty selection.

**6.7.7.3 Array declarators**

4 [...] (The declaration of variable length arrays with automatic storage duration are a conditional feature that implementations may support; see 6.10.10.4.)

**6.10.10.4 Conditional feature macros**

**\_\_STDC\_NO\_VLA\_\_** The integer literal 1, intended to indicate that the implementation does not support the declaration of variable length arrays with automatic storage duration. Parameters declared with variable length array types are adjusted and then define objects of automatic storage duration with pointer types. Thus, support for such declarations is mandatory.

**\_\_STDC\_ARRAY\_SELECTIONS\_\_** The integer literal 1, intended to indicate that the implementation supports array selections beyond empty selections. Otherwise the macro shall not be defined or defined to 0.

If the implementation supports only empty selections, the following macros may not be defined. If defined, the first one shall be defined to 0.

**\_\_STDC\_ARRSEL\_NESTED\_\_** The integer literal 0 if selections of the form [B:L] and [B:L:s] can only be applied to expressions of pointer type and to arrays carrying no selection or an empty selection, and range operations are allowed only if the selected elements from the matrices treated as a range of objects are singletons. The integer literal 1 otherwise.

**\_\_STDC\_ARRSEL\_STEPPED\_\_** The integer literal 0 if selections of the form [B:L:s] are not supported; the integer literal 1 if they are.

* TODO:
1. Talk about how an implementation may translate range operations.
2. About forgetting the selection and reselecting. That it makes translation more difficult.
3. Example of the small shape in the middle of a matrix. Move it (the shape).
4. broken, selected, collapsed (in future extensions). these are supertypes. Split carryng a selection from (potentially-)broken.
5. The wording of the constraint of the & operator.
6. Extension: addresses of arrays with selection.