C Language Constructs for Parallel Programming

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Cilk Plus

Parallel tasks	 Easy to learn: 3 keywords Tasks, not threads Load balancing 	
Hyper Objects	 Mitigate data races on non-local variables 	
Array notations	 Data-parallel array operations Targets SIMD 	
Elemental Functions	 Data-parallel function mapping 	
SIMD Loops	 Vectorization annotation for loops Single threaded vector parallelism 	



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cilk_spawn and cilk_sync Keywords

```
int tree_walk(node *nodep)
                                                   Asynchronous recursive
   {
                                                        call to tree wak
         int a = 0, b = 0;
         if (nodep->left)
               a = _Cilk_spawn tree_walk(nodep->left);
         if (nodep->right)
               b = _Cilk_spawn tree_walk(nodep->right);
         int c = f(nodep->value);
         _Cilk_sync;
                                                   Call to f() can run in parallel
         return a + b + c;
                                                     with recursive tree walks
   }
        Implicit sync at the end of every function keeps code well structured
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```

"Serialization" of Tree-walk Example

```
int tree walk(node *n)
{
    int a = 0, b = 0;
    if (n->left)
                         tree walk(n->left);
        a =
    if (n->right)
                         tree_walk(n->right);
        b =
    int c = f(n->value);
    return a + b + c;
}
```

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Example of keyword vs. pragma

 $X = f1(a,b) + Cilk_spawn f2(c,d);$

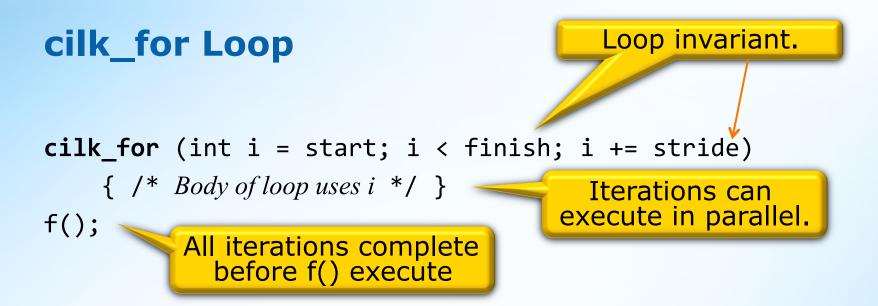
X =_Cilk_spawn f1(a,b) + f2(c,d);

- The above is currently disallow in Cilk Plus
 - But this is not a necessary restriction
 - Can be allowed
- The pragmas are separate from the C expression
- Hard to point out an exact point within a sub expression



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The loops has to be a countable loop Multiple linear increment allowed



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Reducer Hyperobjects

```
    "Traditional" reduction on a parallel for loop:

long a[sz];
reducer_opadd<int> sum = 0;
cilk for (int i = 0; i < sz; ++i)
    sum += a[i];
                              Parallel accesses each
                               get their own "view"

    Generalized reduction for any code executing in parallel:

reducer opadd<int> sum = 0;
void sum_tree(node* nodep) {
  if (nodep->left) cilk_spawn sum_tree(nodep->left);
  if (nodep->right) cilk spawn sum tree(nodep->right);
  sum += nodep->value;
}
```

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Array Notation Example

```
    Serial Example

float dot_product(unsigned int sz,
                       float A[], float B[]) {
     float dp=0.0f;
     for (int i=0; i<size; i++)</pre>
           dp += A[i] * B[i];
     return dp;
}

    Array Notation Version

float dot product(unsigned int sz,
                       float A[], float B[]) {
     return ___sec_reduce_add(A[0:sz] * B[0:sz]);
  Intrinsic reduction
                                               Element-wise
                                Array
                                                multiplication
                               Section
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```

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8

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Rank and Shape

An array section doesn't have a new kind of type

- the type of an array section is exactly that of the analogous subscript expression.
- Additionally, an array section has rank and shape.
- A section implicitly iterates over some elements of an array.
 - Rank is the number of levels of loop nesting (i.e. dimensions) in the iteration space.
 - Shape is a (mathematical) vector of lengths. (The rank is the same as the length of the shape vector.)



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Rank and Shape (continued)

 The rank of an expression is determined statically. In general the shape of a section is determined dynamically.

Expression	Rank	Shape
a[0]	0	
a[0:n]	1	n
a[0][i:10]	1	10
a[i:n][j:m]	2	n×m



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Shapes have to match

- If array size is not known, both lower-bound and length must be specified
- Section ranks and lengths ("shapes") must match.
 - Scalars are OK.

a[0:5] = b[0:6]; // No. Size mismatch. a[0:5][0:4] = b[0:5]; // No. Rank mismatch. a[0:5] = b[0:5][0:5]; // No. No 2D->1D a[0:4] = 5; // OK. 4 elements of A filled w/ 5. a[0:4] = b[i]; // OK. Fill with scalar b[i]. a[10][0:4] = b[1:4]; // OK. Both are 1D sections. $b[i] = a[0:4]; // No. 1D \rightarrow 0 D$

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Array Notations → **Vector Operations**

Selection of array elements

 "vector" refers to a 1D array. Current implementation is does not allow [:] to be overloaded, e.g., for std::vector.

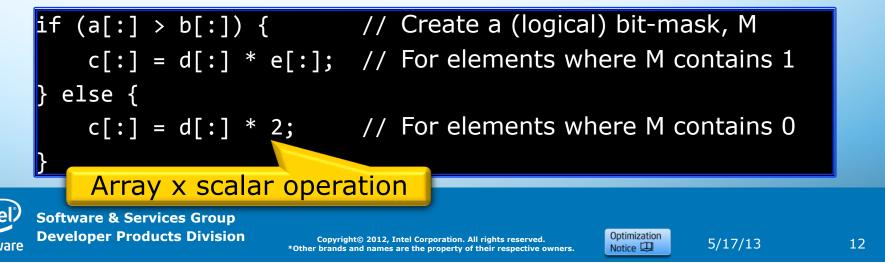
A[:] // All of vector A

B[2:6] // Elements 2 to 7 of vector B

C[:][5] // Column 5 of matrix C

D[0:3:2] // Elements 0,2,4 of vector D

Masked vector operations



Vector Loop: Order of Evaluation

```
simd_for (int n = 0; n < N; ++n) {
    a[n] += b[n];
    c[n] += d[n];
}</pre>
```

Uniform vs. Private: Illustration

```
double b = get_position();
simd_for (int i = 0; i < N; ++i) {
    double t;
    t = y[i] * cos(z[i]);
    a[i] = t / b;
}
```

- b is uniform, t is private
 - The proposal is mapping the concepts of a uniform and a private variables onto existing syntax
- Assignments to b inside the loop shall result in uniform values, otherwise the behavior is undefined.



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Elemental Functions - Example

• Defining an elemental function:

```
double option_price_call_black_scholes(
    double S, double K, double r,
    double sigma, double time) _Simd
{
    double time_sqrt = sqrt(time);
    double d1 = (log(S/K)+r*time)/(sigma*time_sqrt) +
        0.5*sigma*time_sqrt;
    double d2 = d1-(sigma*time_sqrt);
    return S*N(d1) - K*exp(-r*time)*N(d2);
}
```

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Illustration

```
void
vec_add ( float *r, float *op1, float *op2, int i)
    simd (chunk (N))
    simd (uniform (r,op1, op2) , linear (i), chunk(N))
{
    r[i] = op1[i] + op2[i];
}
```

```
Two vector versions and one scalar
```

```
ssimd_for (int i = 0; i<N; ++i) {
    vec_add(a,b,c,i);
}</pre>
```

```
simd_for (int i = 0; i<N; ++i) {
    vec_add(a[x1[[i]],b[x2[[i]],c[x3[[i]],i);
}</pre>
```

Call matches the version with the uniforms

Call matches the version w/o the uniforms

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3

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Joint proposal between Cilk Plus and OpenMP

- A minimal language
- The language does not mandate a scheduling technique
- The language allows / does not disallow dynamic load balancing
- Serial semantics and serial equivalence
- Well integrated into the C language



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