Library Oriented Approaches for Parallel Loop Constructs

Outline

- Parallelism Intro
  - Loops and Blocks
  - The Challenge of Loop Reduction
- Paraffin
  - Design
  - Capabilities
  - Examples
- Syntax Helpers?
  - Goal: Integrate with libraries
  - What can be done?

Where Ada stands to shine

- Ada's focus on correctness
- Static checking
  - Let compiler find problems when possible
  - Catch bugs earlier in development.
- Parallel Programming is difficult to get right.
  - Let Ada compiler help programmer out as much as possible.
- Ideally Ada would prevent data races
  - Other languages let programmers shoot themselves in the foot more readily.

Parallelism Constructs

- Basically two constructs needed
  - Parallel Blocks
    - Forking two or more actions in parallel.
  - Parallel Loops
    - Simple Iteration loops
    - Reduction loops
    - Container Iteration

Parallel Blocks

- When Two or more lengthy actions can execute at the same time.

```
Paint_Sistine_Chapel;   -- 1502 - 1512
Paint_Mona_Lisa;        -- 1503 - 1506
```

- Doesn't work so well with just one worker
  - But with two or more workers, works great!
- Same goes for;

```
Build_Rome;  -- Took longer than a day
```

  - A classic Divide and Conquer problem

Parallel Blocks Works well with Recursion

- Leonardo Bonacci (c. 1170 – c. 1250)
  - Known also as Leonardo of Pisa
  - You might know him by his other name;
    - Leonardo Fibonacci
      - popularized the Hindu–Arabic numeral system
      - Wrote Liber Abaci in 1202
        - A historic book on Arithmetic
        - Among many other things, introduced the Fibonacci sequence

Recursive Parallel Fibonacci

Fn = Fn-1 + Fn-2 {0,1,1,2,3,5,8,13,21,34,55,89,...}

```
function Fibonacci (N : Natural) return
  Natural is
begin

   if N < 2 then
      return N;
   end if;

   return Fibonacci (N - 2) +
          Fibonacci (N - 1);
end Fibonacci;
```

Opportunity for Divide & Conquer

Rework for Parallelism

```
function Fibonacci (N : Natural) return Natural
is
   Left, Right : Natural;
begin
   if N < 2 then
      return N;
   end if;

   parallel
      Left  := Fibonacci (N - 2);
   and
      Right := Fibonacci (N - 1);
   end parallel;

   return Left + Right;
end Fibonacci;
```

Calculation of Left & Right occur in parallel

Synchronization occurs here

Parallel Loops

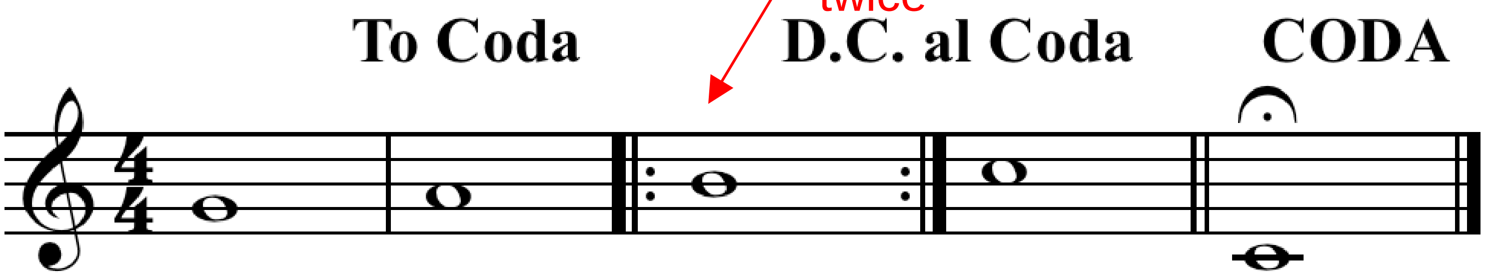
Go back to the Beginning

- Same action occurring multiple times

Italian Music Term: **Da Capo (D.C.)**

Italian goto statement

Nested Loop Middle Bar plays twice




```
for Verse in 1 .. 2 loop
   Play (Bar1, G1, 4s); Play (Bar2, A2, 4s);
   if Verse = 1 then
      for Repeat in 1 .. 2 loop
         Play (Bar3, B2, 4s);
      end loop;
      Play (Bar4, C2, 4s);
   end if;
end loop;
Play (Bar5, C1, 6s);
```

Make this a parallel loop
(We might get Jazz!)

Biggest challenge for parallelism syntax

- Loop Reductions (by far)
  - Combining parallel results into a single overall result

Global result, need to avoid data races

```
Sum := 0;
for I in 1 .. N loop
   Sum := Sum + I;
end loop;
```

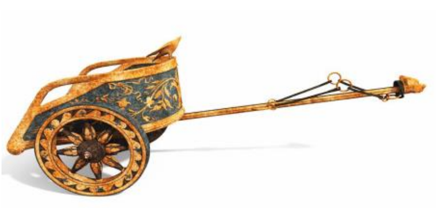
Need to be able to run this loop in parallel, But how?

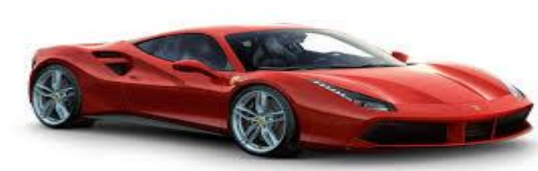
Benefits of Syntax

- Can be tailored to “suit” a particular problem
  - Has to “fit” in the language, however
- Compiler can have more intimate knowledge
  - eg. Detect data races
- Can be easier to read and write
- Examples of syntactic solution
  - OpenMP (C, C++, FORTRAN)
  - Cilk (C, C++)

Other side of Syntax

- Adds complexity to language definition
- More work for compiler writers
- Danger of unseen problems, or regrets
  - Once something is in Standard, there for good
- Might think of better idea down the road
  - As new hardware and computing platforms arise





- All roads might lead to Rome...
  - but some get us there faster. (Parallelism goal)

Other extreme – Library Approach

- Libraries can be written today using existing syntax (Examples C#, Java)
- Generally easier to implement a library than syntax
- No additional complexity for language definition
- Syntax tends to be generalized
- Libraries can more easily adapt to specific needs
  - Controls, Parameters, Variants, etc

The syntax spectrum

- No need to stick with one extreme or the other
- Might be a middle ground that combines more general syntax with a library approach...
  - The more places new syntax can be used...
    - Generally means more useful
- Other possibility is to provide both
  - Libraries for those who want less “magic”
  - Syntax for those that want ease of expression

Library approach

- How far can we go?
  - To make libraries easy to use
    - Specifically parallelism libraries
  - Maybe sprinkle on some syntactic sugar?
  - Eg. Ada Containers + Ada 2012 Iterator Syntax

```
for Element of Container loop
   Element := Element + 1;
end loop;
```

Paraffin – A study in parallelism libraries

- Features
  - Written in Ada
  - Parallel Loops
  - Parallel Blocks
  - Parallel subprograms
  - Task Pools (optional)
  - Ravenscar (optional)
  - Non-commutative reduction (optional)

Paraffin – Features (Cont)

- Support for multilangage use
  - C, C++, C#, Java, FORTRAN, Python, Rust
- Bindings to OpenMP and Cilk
- Native Paraffin implementations as well
- Stack safe parallel recursion
- 3 native load balancing strategies
  - Work Sharing, Work Seeking, Work Stealing
- Supports for Ada 95, Ada 2005, and Ada 2012
- At least two different compiler vendors
  - Adacore + ICC Irvine Compiler

C# Interfacing to Paraffin

```
class test_paraffin_lib
 {
   [ThreadStatic]
   private static int partial_sum;

   static void Main(string[] args)
   {
    int sum = 0;

    paraffin_pkg.parallel_loop
       (from : 1, to: 400000000,
        reset: () => { partial_sum = 0; },
        process: (start, finish) =>
          {  for (int i = start; i <= finish; i++)
                   partial_sum += i;
          },
        reduce: () => { sum += partial_sum; });
```

Paraffin Library API

```
generic
   type Loop_Index is range <>;
   type Result_Type is private;
   with function Reducer
         (Left, Right : Result_Type)
            return Result_Type;
   Identity_Value : Result_Type;
package Parallel.Generic_Reducing_Loops is

   function Parallel_Loop
     (From, To   : Loop_Index;
      Loop_Body  : not null access
        procedure (From, To : Loop_Index;
                   Result   : in out Result_Type))
   return Result_Type;

end Parallel.Generic_Reducing_Loops;
```

Calling Paraffin From Ada Today

```
package Loops is new
   Parallel.Generic_Reducing_Loops
             (Loop_Index  => Integer,
              Result_Type => Integer,
              Identity    => 0,
              Reducer     => "+"); use Loops;

procedure Loop_Body
   (Start, Finish : Integer;
    Partial_Result : in out Integer) is
begin
  for I in Start .. Finish loop
     Partial_Result := Partial_Result + I;
  end loop;
end Loop_Body;

Sum := Parallel_Loop (From => 1, To => N,
                      Loop_Body => Loop_Body'Access);
```

Idea #1 Lambda Procedures

```
Sum := Parallel_Loop
   (From      => 1,
    To        => N,
    Loop_Body => (Start, Finish, Result)
       (for I in Start .. Finish loop
           Result := Result + I;
        end loop));
```

Idea #2 Loop Body Procedures

```
for (Start, Finish, Result) of
     Parallel_Loop (From => 1,
                    To   => N) loop
   for I in Start .. Finish loop
      Result := Result + I;
   end loop;
end loop;
```

Idea #3 Stream Function Loops

- Java takes a unique approach with Java Streams
- Functions are pipelined together
  - A library approach

int sum = IntStream.range(1,N).parallel().sum();

Delete “Parallel”
to get Sequential loop

Collector function terminates Stream

Idea #3 Stream Function Loops

```
Sum := 0;

for I of Iter(1,N).Parallel.Add(Sum) loop
   Sum := Sum + I;
end loop;
```

Idea #3 Stream Function Loops Container Iteration example

```
-- Iterating through a map containers keys.
for Pair of Container.Keys loop
    Put_Line(Key_Type'Image(Pair.Key) &
             " => " &
             Elem_Type'Image(Pair.Elem));
end loop;

Total : Integer := 0;

for V of Container.Elements.Sum(Total) loop
  Total := Total + V;
end loop;
```

Summary

- A blend of libraries + general loop syntax can express a parallel loop quite nicely
- Desire to represent parallel loops as loops
- Desire to represent functions as functions
- Which one wins? Maybe we need both?
- Combining Java Stream idea with idea for loop procedure bodies seems like a good way to express parallelism with minimal syntax.

Questions? Comments?

- Thank you!