CS225 Lab11: Reductions with OpenMP

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Motivating example: Finding a vector's sum

- Consider the following code for finding the sum of the integers in a vector.

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- Can this be parallelized?
- Not trivially. Why? What happens with the `sum` variable?

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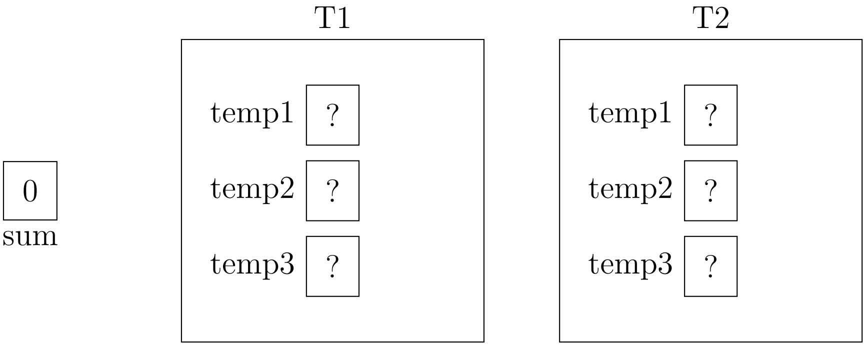
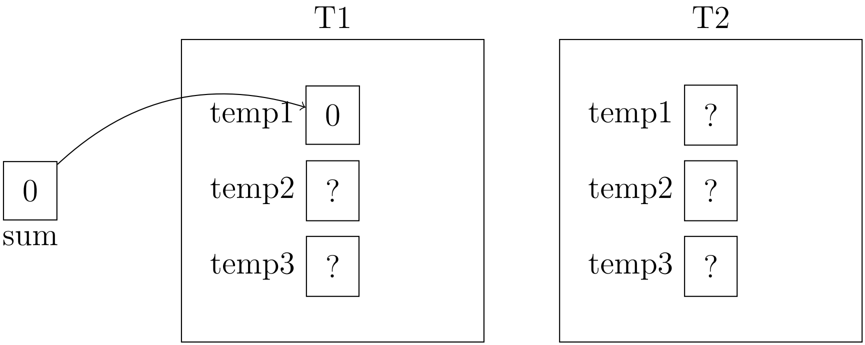
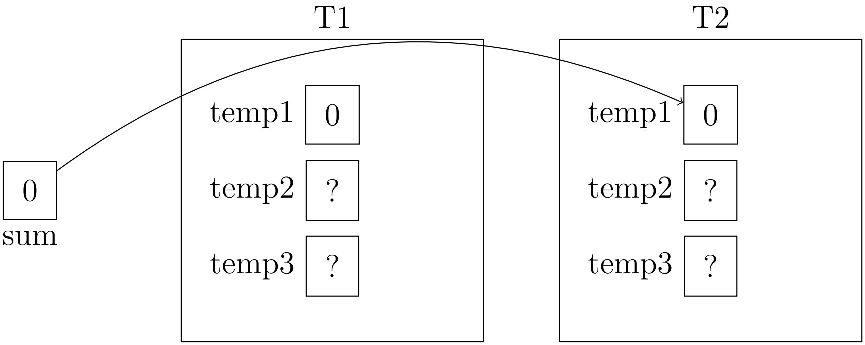
- Each CPU core (which runs a thread) can only perform arithmetic on things that are currently loaded in.
- Need to load in `sum` and `list[i]` before they can be added.
- Then the result must be stored back into memory.
- But why is this a problem? What happens if we interleave these multiple machine instructions?


0
sum
T1
temp1 ?
temp2 ?
temp3 ?
T2
temp1 ?
temp2 ?
temp3 ?


T1
T2
temp1
0
temp2
?
temp3
?
temp1
?
temp2
?
temp3
?
0
sum


T1
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temp3
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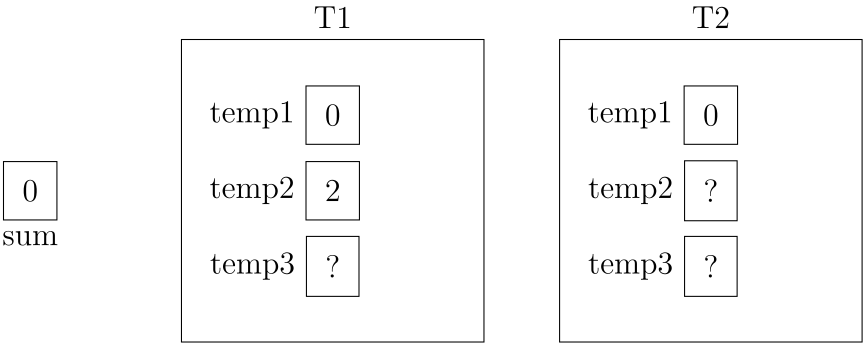
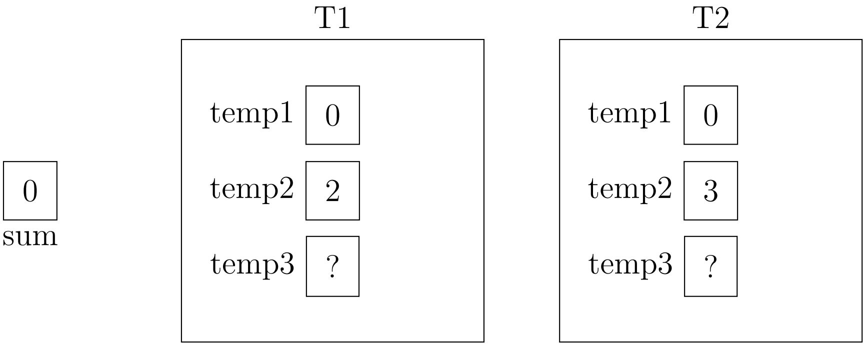

T1
T2
temp1
0
temp2
2
temp3
?
temp1
0
temp2
?
temp3
?
0
sum


T1
T2
temp1
0
temp2
2
temp3
?
temp1
0
temp2
3
temp3
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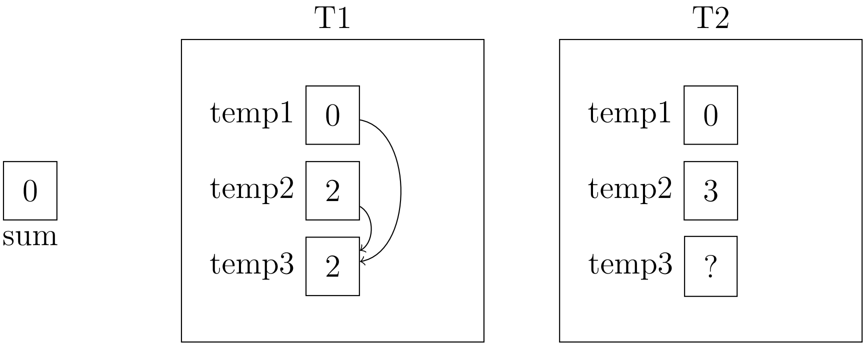
sum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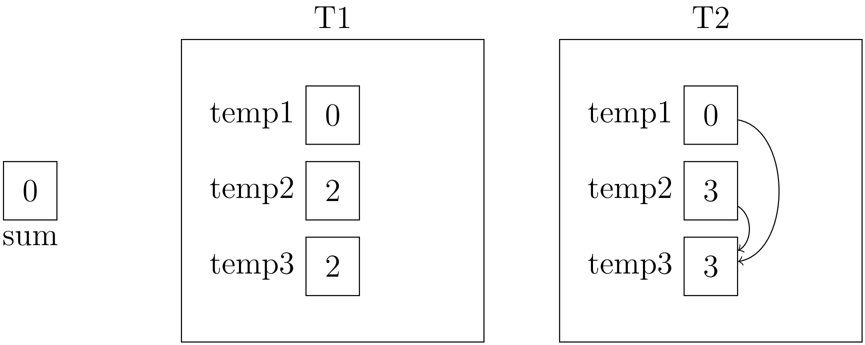
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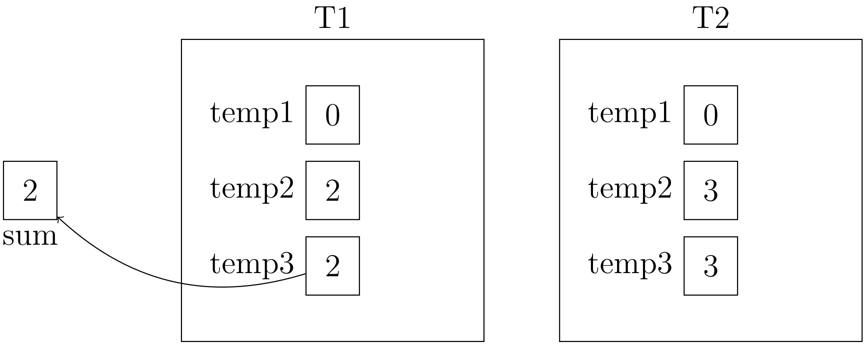
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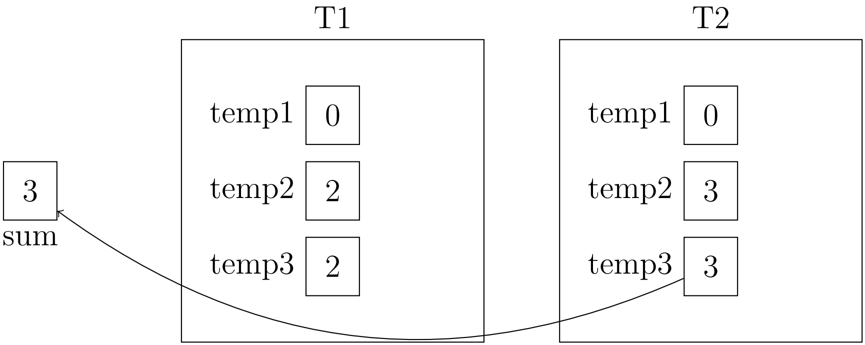
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- $\sum_{\forall a \in T}(a)$ (that is, sum up the values in T)
- This step is an example of a *reduction*.

Reductions

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- A *reduction* is an operation applied to an array to produce a result of a lesser rank.

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- In our example, we have an array of results, T from each thread's subproblem.
- If x is the answer computed in a parallel subproblem, we run a "reduction on x" to get our final answer.

Reductions in OpenMP

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     - This is a useful shorthand, but it isn't always an option for more complicated reduction statements.
  2. Manually fix the race condition on the reduction variable.
     - This is always an option, regardless of the complexity of the reduction statement.

Critical Regions and Atomicity

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- We guarantee critical regions are **atomic** by only allowing one thread to execute in the critical region at a time.
- How can we use the idea of a “critical region” to help manually fix the race condition on the `sum` variable?

Example: Manual Reduction With a Critical Region

```
int findSum(const vector<int> & list) {
  int sum = 0;
  #pragma omp parallel
  {
    int local_sum = 0;
    #pragma omp for
    for( int i = 0; i < list.size(); i++ )
      local_sum += list[i];
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  - Designates the given block of code as a "critical region".
  - Only one thread in the team is allowed to be executing in the critical region at a time.
  - This fixes our race condition!

Execution Diagram

What does this look like when running?

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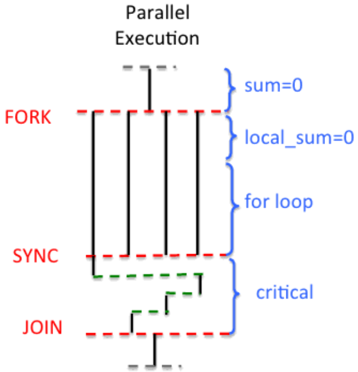

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- The "reduction clause" comes after a for construct and takes the form `reduction(operator: variables)`.
- The `operator` can only be of the following: $+$, $*$, $-$, $/$, &, ^, $|$, &&, $||$.
- It *cannot be overloaded*.
- The elements provided as `variables` must be scalar (primitive) types.

Example: Using the Reduction Clause

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This is shorthand for resolving the race condition manually.

Another Example: Largest Integer Problem

- Consider the code below for finding the maximum integer in an array.

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int findMax( const vector<int> & list ) {
    int max = INT_MIN;
    for( int i = 0; i < list.size(); i++ )
        if( max < list[i] )
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- Full disclosure: This will eventually be possible with a reduction clause in OpenMP 3.1 (supported in GCC 4.7).

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Filling in the code:

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- In general, the reduction clause can only be used if our reduction is a simplistic one.
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- In our examples, our `parallel for` directive is our mapping function, and our reduction setup is the reduce step.

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- **Reductions** can help us assemble a main result from a list of results of parallel subproblems.
- There is a subset of Race conditions that can be resolved by using **reductions**.
- The general paradigm in use here is the same as that used in **Mapreduce**!