

# TENTAMEN / EXAM

## TDDC78

Programmering av paralleldatorer /  
Programming of parallel computers

2014-08-19, 14:00–18:00, TER3

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**Hjälpmedel / Allowed aids:** Engelsk ordbok /  
dictionary from English to your native language

**Examinator:** Christoph Kessler

**Jourhavande lärare:**

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**Maximalt antal poäng / Max. #points:** 40

**Betyg / Grading (prel.):** The preliminary threshold for passing (grade 3) is at 20p, for grade 4 at 28p, for grade 5 at 34p.

Because of new regulations by Linköping University, we can no longer give ECTS grades. If you should need one, please contact the course secretary after the result has been entered in LADOK.

### General instructions

- Please use a new sheet of paper for each assignment. Order your sheets by assignments, number them, and mark them on top with your exam ID number and the course code.
- You may answer in either English or Swedish. **English is preferred** because not all correcting assistants understand Swedish.
- Write clearly. Unreadable text will be ignored.
- Be precise in your statements. Unprecise formulations may lead to a reduction of points.
- Motivate clearly all statements and reasoning.
- Explain calculations and solution procedures.
- The assignments are *not* ordered according to difficulty.

1. (7 p.) **Performance tools and analysis**

- (a) (1.5p) Compare performance data collection with hardware counters vs. software counters.  
What has, in each case, to be done with the program (technically) to enable this data collection?  
What is the main advantage of using hardware counters (where applicable) compared to software counters?
- (b) (1 p.) Which performance data collection method is required in order to be able to draw a processor-time diagram (also known as a *Gantt chart*)? Justify your answer (technical reasons).
- (c) (1p) Which aspect of parallel computation is modeled well by the PRAM (Parallel Random Access Machine) model, and which important property / properties of real parallel machines does it abstract from?
- (d) (1p) When is a parallel algorithm for some problem (asymptotically) *cost-optimal*? (*give a formal definition*)
- (e) (1p) There exist several possible causes for *speedup anomalies* in the performance behavior of parallel programs. Name and explain one of them.
- (f) (1.5p) How is the so-called *peak performance* of a parallel computer system such as Triolith calculated? (*give a commented formula*) (1p)  
And why does the peak performance generally differ significantly from the ( $R_{max}$ ) performance obtained for the LINPACK benchmark? (0.5p)

2. (2 p.) **Parallel programming models**

Explain the parallel program execution styles *fork-join* and *SPMD*, and explain the main difference. (1p)

Which one is more comfortable for the programmer, and why? (0.5p)

Which one is used in MPI? (0.5p)

3. (4 p.) **Parallel program design methodology**

Foster's design methodology consists of four stages. Name and explain them. Give details about their goals. What are the important properties of the result of each stage? Be thorough!

4. (5.5 p.) **Parallel computer architecture**

- (a) (0.5p) What does *Moore's Law* really say? Be precise!  
(*Hint 1: Does Moore's Law still hold today? — Hint 2: Is Moore's Law a law in the mathematical sense?*)
- (b) How does the MSI *write-invalidate protocol* for cache coherence in a bus-based shared memory system work? (*Be thorough*) (2p)

- (c) (3p) Explain the *2D-Torus* interconnection network topology. (0.5p)

Determine its maximum node degree, the maximum distance of any two nodes, and the maximum aggregated bandwidth (given by the maximum possible number of communications proceeding simultaneously in the network). (1.5p)

Shortly describe one kind of computation problem (e.g., from your labs) for execution on a message passing environment, for which a 2D-Torus network would be more efficient than its 1D equivalent, and why. (1p)

5. (4 p.) **OpenMP**

- (a) OpenMP provides different scheduling methods for parallel loops. Characterize the kind of loops that are expected to perform best with *static scheduling*, and explain why. (1.5p)

- (b) (2.5p) Given the following example loop:

```
s = 0.0;
#pragma omp parallel for shared(s)
for (i=0; i<N; i++)
    s = s + A[i];
```

(i) There is a correctness problem with this code. Explain, and suggest a simple fix that however leads to a scalability problem.

(ii) Apply the **reduction** clause properly to the example loop and show what kind of code (commented pseudocode) the compiler generates for this loop. Explain why it fixes both the correctness issue and the scalability problem.

6. (5 p.) **Parallel Basic Linear Algebra**

- (a) (3p) The BLAS (Basic Linear Algebra Subroutines) library API comes in three different levels (BLAS Level 1, 2, 3).

(i) Name one representative function from each level and give a short description. (1.5p)

(ii) Why is it very important for a supercomputing center to have efficient implementations of BLAS installed? (0.5p)

(iii) Which of the levels is most likely to have efficient parallel implementations even where interprocessor communication is expensive, and why? (1p)

- (b) (2p) Consider the following straightforward sequential code for the multiplication of two  $N \times N$  square matrices  $A$  and  $B$ :

```
for (i=0; i<N; i++)
    for (j=0; j<N; j++)
        C[i][j] = 0.0;
for (i=0; i<N; i++)
    for (j=0; j<N; j++)
        for (k=0; k<N; k++)
            C[i][j] = C[i][j] + A[i][k] * B[k][j];
```

Apply *tiling* with tile size  $S \times S$  (with  $1 < S \ll N$ ) to the second loop nest. Show the resulting pseudocode.

Why is tiling (with a suitably chosen  $S$ ) beneficial for the performance of this code on modern processor architectures?

## 7. (7 p.) **Parallel Solving of Linear Equation Systems**

(a) Straightforward message passing implementations for Gaussian Elimination (and similarly, LU decomposition) expose a *load balancing problem* for row-block-wise and column-block-wise distributions of the system matrix  $A$ . Explain the cause of the load balancing problem (be thorough!) and how it could be solved (to most degree). (2p)

(b) (5p) *Column pivoting* searches in each step  $k$  of Gaussian Elimination within column  $k$  for an element  $a_{i,k}$  with maximum absolute value and then exchanges entire row  $i$  with row  $k$  (unless just  $i = k$ ) before the updating of submatrix  $A_{k..n-1,k..n-1}$  of step  $k$  is being performed.

For a *row-block-wise* distribution of the system matrix  $A$ , describe the required additional computation and communication operations for column pivoting, and give its parallel time cost as a formula in  $k$  and  $n$  for the delay model.

For the above analysis, use the delay model, assuming for simplicity that the underlying interconnection network is fully connected (i.e., each processor has a direct network link to every other processor) with message startup time  $\alpha$  (clock cycles) and average (float) word transfer time  $\beta$  (clock cycles), and that a processor can only send or receive one message at a time. If you need to make further assumptions, state them carefully.

## 8. (1.5 p.) **Transformation and Parallelization of Sequential Loops**

Given the following C loop:

```
for (i=0; i<N; i++) {  
    a[i+1] = 2.0 * a[i] / b[i] + c[i];  
}
```

(a) Explain why the loop iterations cannot be executed in parallel in this form (dependence-based argument). (0.5p)

(b) For the following loop

```
for (i=0; i<N; i++) {  
    a[i] = 2.0 * a[i+1] / b[i] + c[i];  
}
```

suggest a (semantic-preserving) transformation of the loop (show the new code) such that the loop iterations now could be executed in parallel. Explain why (dependence-based argument). (1p)

9. (3.5 p.) **MPI**

- (a) How does the *nonblocking* (also called *incomplete*) send routine `MPI_Isend` differ from the ordinary blocking `MPI_Send`?

Under what condition is it safe to replace a `MPI_Send` call by `MPI_Isend`? (1.5p)

- (b) (2 p.) *One-sided communication in MPI*

- i. Explain the principle of one-sided communication in MPI-2. (1p)

*Hint: You might want to illustrate your answer with a pseudocode example and/or an annotated picture.*

- ii. Why is one-sided communication considered being “closer” to the shared-memory programming model than ordinary two-sided message passing? (0.5p)
- iii. How does one-sided communication still differ from the shared-memory programming model? (0.5p)

10. (0.5 p.) **Grid Computing**

Name one task performed by *grid middleware*.