

COURSE REVIEW

COMP4300/8300 PARALLEL SYSTEMS

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Australian
National
University

Assignment 2 & Final Exam

- **Assignment 2** is worth 25% of your final mark and is due this Monday **26/05/2025, 11:55PM**
- Once again, the report has a large relative weight in the final mark, and should be well-written. Submissions without a report will get a very low mark.
- Final Exam will be held on **Wednesday 11/06/2025 at 2:00pm at Copland G31 (Building 24)**
 - The exam will be in-person, open-book (lecture notes only), paper and pen, with invigilation. No electronic devices will be allowed (including laptops, smart-watches, calculators, etc.)
 - The Final Exam (FE) is worth 40% of the final mark

Final Exam

- Three-hour pen-and-paper exam with a 15-minute reading time
- Multiple choice questions with content spanning all main course topics – **25 marks**
- Three sections– **each worth 25 marks**– with more specific questions requiring more detailed answers and/or problem solving
 - Distributed Memory Parallel Systems Architecture and Programming
 - Shared Memory Parallel Systems Architecture and Programming
 - GPU Architecture and Programming
- Each of last the three sections will contain 3-6 questions on its specific topic

Final Exam Preparations

- All examples in this presentation are taken from past exam papers which are accessible on Wattle.
- Exercising on the past final exams is a very good training for the final exam.
- Of course, the exam will not contain any topic that has not been discussed this year.

Final Exam Preparations – Key topics

- Classical Parallel Hardware (Flynn Taxonomy, UMA and NUMA Architectures, Distributed- and Shared-Memory Systems)
- Instruction Level Parallelism (Superscalarity, Pipelining, Out-of-order execution)
- Dynamic and Static Connectivity Networks
- Message Passing and MPI (Point-to-Point Communications, Blocking and Non-Blocking Communication, Collectives, Datatypes)
- Strong and Weak Scaling, Parallel Speedup and Efficiency
- Network Routing, Communication Cost, Performance Modelling Part I: Synchronous Computations
- Pipelining and Divide & Conquer Parallelization

Final Exam Preparations – Key Topics

- Motivation for Shared Memory Parallel Computers (Dennard Scaling, Moore's Law, Limitations of ILP)
- Process versus Thread Parallelism
- Pthreads, Thread Memory and Execution Models
- Thread Synchronization (state diagrams, critical section, semaphores, mutexes & locks)
- The OpenMP Programming Model
- Simultaneous Multi-Threading, Single Instruction Multiple Data Part II: GPU Execution Model
- GPU Memory Model
- The CUDA Programming Model
- Snooping-Based Cache Coherence
- Roofline

Distributed Memory Parallel Systems Architecture and Programming (DMEM)

- Determine performance/cost of DMEM algorithms on a given network topology
- Implement and/or optimize DMEM algorithms using MPI
- Explain semantics of, or amend, a presented MPI code

DMEM: Examples

- (b) Explain what the following MPI program is doing, and state the output that is printed if the code is run using 7 MPI processes:

```
int main (int argc, char *argv[]) {
    int token, NP, myrank;
    MPI_Status status;
    MPI_Init (&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD, &NP);
    MPI_Comm_rank(MPI_COMM_WORLD, &myrank);
    if (myrank != 0) {
        MPI_Recv(&token, 1, MPI_INT, myrank - 1, 0, MPI_COMM_WORLD, &status);
    } else {
        token = -1;
    }
    token += 2;
    MPI_Send(&token, 1, MPI_INT, (myrank + 1) % NP, 0, MPI_COMM_WORLD);
    if (myrank == 0) {
        MPI_Recv(&token, 1, MPI_INT, NP - 1, 0, MPI_COMM_WORLD, &status);
    }
    printf("rank and token %d %d \n", myrank, token);
    MPI_Finalize();
}
```


DMEM: Examples

Consider the following algorithm which runs p processors, where p is a power of two and where i ($0 \leq i < p$) is the id of the executing process:

```
int x[m];  
...  
for (d = p/2; d > 0; d /= 2) {  
    if (i % (2*d) == 0)  
        send(x, m, i+d);  
    else if (i % (2*d) == d)  
        recv(x, m, i-d);  
}
```

Let t_s be the message startup time, t_w be the transmission cost per unit word, and t_h be the per-hop transmission link latency. Derive expressions for the parallel execution time under a ring topology for both store-forward (SF) routing and cut-through (CT) routing. Give a simple approximate expression for the time reduction ratio of CT over SF, listing any assumptions made.

Shared Memory Parallel Systems Architecture and Programming (SHMEM)

- Implement and/or optimize SHMEM algorithms using OpenMP
- Explain semantics of, or amend, a presented OpenMP code
- Discuss shared memory processor architecture, execution and memory models

SHMEM examples

- Implement and/or optimize SHMEM algorithms using OpenMP
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SHMEM examples

- (a) Parallelize the following code using openMP pragmas. Assume that the target machine has a cache line size of 128B, that the size of an int is 4B, and the arrays contain ints. Be sure to explicitly specify the “schedule” options that should be used, even if you want to use the default options. For each please rewrite as much code as necessary to make your intent clear. If necessary you can assume that the variable P represents the number of processors to be used. Assume that N is large (in the tens of thousands or more). You must explicitly list all variables within the range of a parallel pragma that are private using the *private()* directive.

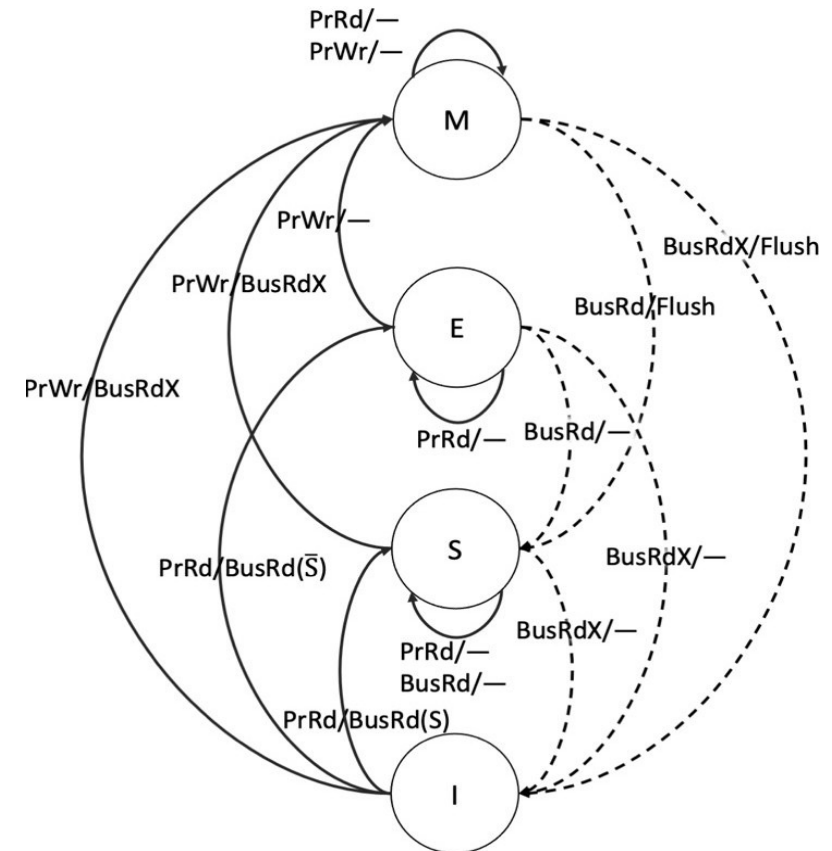
```
(i) for (i=0;i<N;i++){  
    for (j=0;j<N;j++){  
        if (A[i*N+j]< B[i*N+j])A[i*N+j]=B[i*N+j];  
    }  
}
```

```
(ii) C[0] = 1;  
for (i=1;i<N;i++){  
    C[i] = C[i-1];  
    for (j=0;j<N;j++){  
        C[i] *= A[i*N+j] + B[i*N+j];  
    }  
}
```

```
(iii) typedef struct element  
{ int value;  
  struct element *next;  
} Element;  
Element *D[N]; // array of pointers to linked lists of varying length  
int C[N];  
...  
for (i=0;i<N;i++){  
    C[i] = computeAverageValueOfAllListElements(D[i]);  
}
```

SHMEM examples

processor action	P1 cache miss/hit, X value	P2 cache miss/hit, X value	Bus transaction (processor action initiated)	Bus snooper transaction	C1 state	C2 state	mem[&X]
No-Op	N/A	N/A	—	—	I	I	0
P1Rd X	miss, 0	N/A	BusRd(S'')	—			
P1Wr X = 4							
P2Rd X							
P1Wr X = X*2							
P2Wr X = X-3							



GPU Architecture and Programming

- Implement and/or optimize GPU algorithms using CUDA
- Explain semantics of, or amend, a presented CUDA code
- Discuss GPU architecture, execution and memory models

GPU Examples

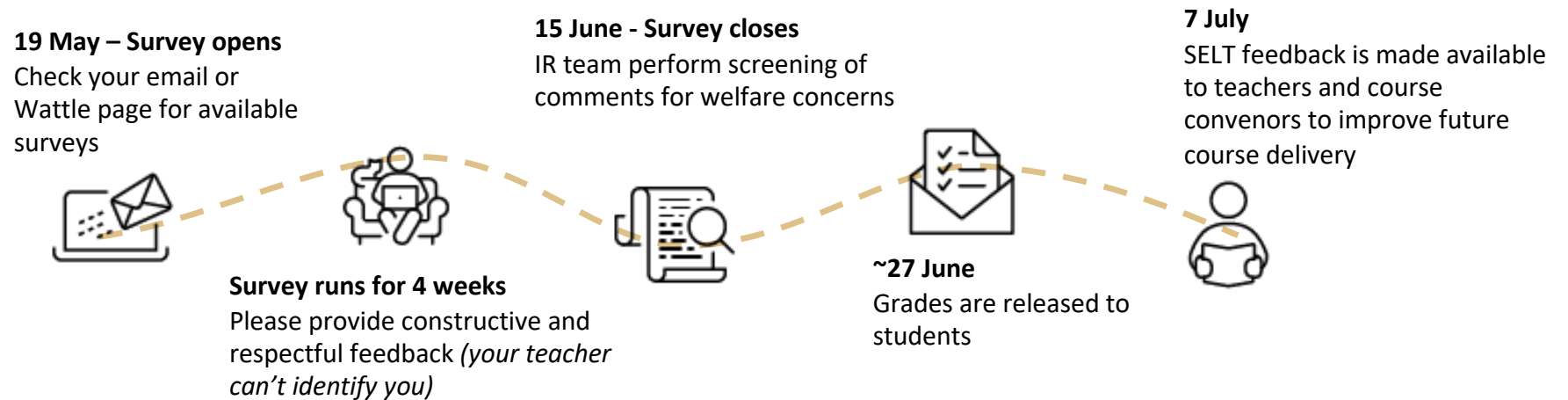
The following code implements the heat diffusion stencil on an M by N column-major matrix t .

```
iter = 0;
do {
    iter++;
    for (j = 1; j < N-1; j++)
        for (i = 1; i < M-1; i++)
            t1[j*N+i] = 0.25*(t[j*N+i+1] + t[j*N+i-1]+
                               t[(j+1)*N+i]+t[(j-1)*N+i]);
    mxdiff = 0.0;
    for (j = 1; j < N-1; j++)
        for (i = 1; i < M-1; i++) {
            tdiff = fabs((double) (t[j*N+i] - t1[j*N+i]));
            mxdiff = (mxdiff < tdiff)? tdiff: mxdiff;
        }
    for (i = 0; i < M*N; i++) t[i] = t1[i];
} while (mxdiff > converge && iter < Max_iter);
```

Write a CUDA kernel to implement the first loop nest, which will work for any (legal) two-dimensional block and thread sizes. For full marks, it should enable contiguous memory accesses within a thread block, but no further optimizations are required.

Semester 1 SELT - survey journey

The Student Experience of Learning & Teaching survey allows students to give feedback on their courses and teachers. It is **voluntary** and **confidential**, and run by the Institutional Research (IR) team.



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Find out more on the *Info for Students* webpage:

<https://services.anu.edu.au/learning-teaching/education-data/student-experience-of-learning-teaching-selt/information-for>



Good luck in the Final Exam!

