Electrical Engineering and Computer Science

EECS 358 - INTRODUCTION TO PARALLEL COMPUTING

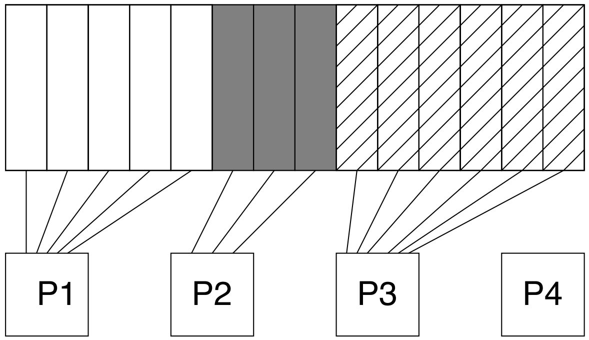
Lecture 5

Shared Memory Programming II

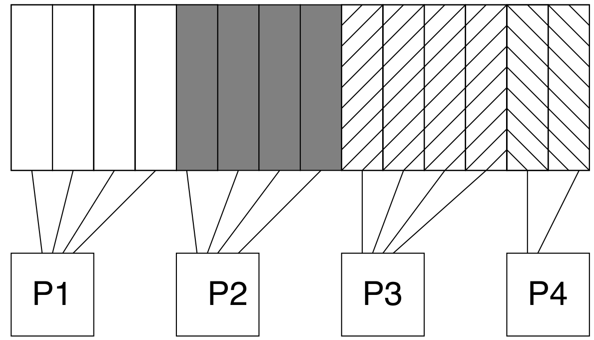
Outline

- Loop scheduling
  - Static
  - Dynamic
- Loop Parallelization
  - Dependence free
  - Dependence situations

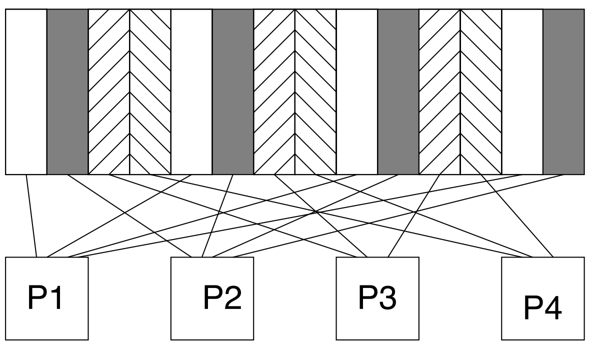
Load Scheduling



(a)



(b)



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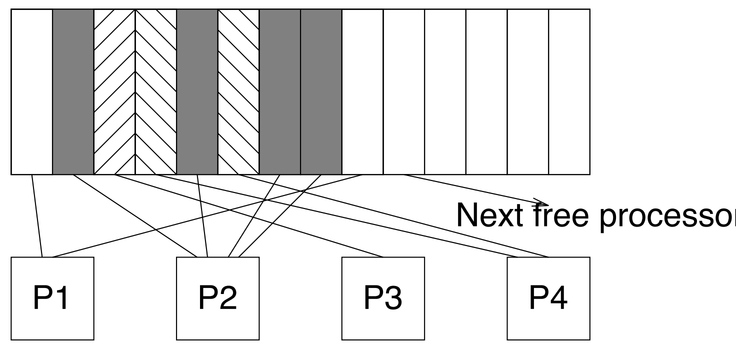

(d)

Loop Scheduling

- Difficult problem in shared memory machines because of load variations on different processors

- A varying number of processors become available over time for on a particular user

- The computation involved in each iteration can itself be widely variant

Loop Scheduling Algorithms

- Consider the following loop:

```
for (i=0; i < 100; i++) {
  a[i] = b[i] * c[i];
}
```

- No dependencies across iterations

- Same amount of work is performed in each iteration

Prescheduling or Indirect Scheduling

- Assign work to each process using a schedule array

```
float *a,*b,*c;
int low[]={0,30,70};
int high[]={30,70,100};

void parallel_func() {
  int id,i;

  id=m_get_myid();
  for (i=low[id];i<high[id];i++) {
    a[i]=b[i]+c[i];
  }
}
```

Static Blocked Scheduling

- Assign a contiguous chunk of iterations based on process id

```
float *a,*b,*c;

void parallel_func() {
  int id,i,nprocs;
  int low,high;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  low=id*100/nprocs;
  high=(id+1)*100/nprocs;
  for (i=low;i<high;i++) {
    a[i]=b[i]+c[i];
  }
}
```

Static Interleaved Scheduling

- Assign iterations in a round-robin fashion based on process id

```
float *a,*b,*c;

void parallel_func() {
  int id,i,nprocs;
  int low,high;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  for (i=id;i<100;i+=nprocs) {
    a[i]=b[i]+c[i];
  }
}
```

Dynamic Scheduling (Self Scheduling)

- Processes execute iterations using a shared counter

```
float *a,*b,*c;
int i;

i = 0;

void parallel_func() {
  int i1,i2;
  int chunk=2;

  while (i1<100) {
     m_lock();
        i1=i;
        i+=chunk;
     m_unlock();
     for (i2=i1;i2<min(i1+chunk,100);i2++) {
       a[i2]=b[i2]*c[i2];
     }
  }
}
```

Dynamic Scheduling (Guided Self Scheduling - GSS)

- Processes execute iterations using a shared counter

```
float *a,*b,*c;
int i;

void parallel_func() {
  int i1,i2,chunk,nprocs;

  nprocs=m_get_numprocs();
  i1=0;
  while (i1<100) {
     m_lock();
        i1=i;
        chunk=(100-i1+1)/(2*nprocs)+1;
        i+=chunk;
     m_unlock();
     for (i2=i1;i2<min(i1+chunk,100);i2++) {
       a[i2]=b[i2]*c[i2];
     }
  }
}
```

Loop Parallelization

- We will look at some simple and commonly occuring code fragments and consider schemes to parallelize them
- Techniques involve the use of:
  - Local variables to remove dependencies
  - Code transformations
  - Use of particular scheduling techniques

Local Variables

- Code fragment:

```
for (i=0;i<n;i++) {
  x=a[i]*3;
  b[i]=x*b[i];
}
```

- Problem: Variable x is dependent, however dependence confined to the same iteration
- Solution: Make x local to each process since each iteration will be completely executed by the same process

Local Variables

```
float *a,*b;
int n;

void parallel_func(n) {
  int i,id,nprocs;
  float x;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  for (i=id;i<n;i+=nprocs) {
    x=a[i]*3;
    b[i]=x*b[i];
  }
}
```

Local Variables

- Code fragment:

```
for (i=0;i<n;i++) {
  x=a[i]*3;
  b[i]=x*b[i];
}
val=foo(x);
```

- Problem: Variation of previous problem, now x is used outside the loop, need the value of x from the last iteration

- Solution: Make x local as before, just ensure the process executing the last iteration of the loop preserves the value of x for further use

Local Variables

```
float *a,*b,x;
int n;

void parallel_func() {
  int i,id,nprocs;
  float local_x;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  for (i=id;i<n;i+=nprocs) {
    local_x=a[i]*3;
    b[i]=local_x*b[i];
    if (i==n-1) x=local_x;
  }
  m_barrier();
  val=foo(x);
}
```

Loop-Carried Values

- Code fragment:

```
indx=0;
for (i=0;i<n;i++) {
  indx+=i;
  a[i]=b[indx];
}
```

- Problem: The value of $indx$ is carried over from iteration to iteration; such a variable is often called an induction variable

- Solution: Substitute a closed form expression for $indx$ in terms of the iteration counter and parallelize

Loop-Carried Values

```
float *a,*b;
int n;

void parallel_func() {
  int i,id,nprocs;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  for (i=id;i<n;i+=nprocs) {
    indx=(i*(i+1))/2;
    a[i]=b[indx];
    }
}
```

Indirect Indexing

- Code fragment:

```
for (i=0;i<n;i++) {
  ix=indexx[i];
  iix=ixoffset[ix];
  total[iix]=total[iix]+delta;
}
```

- Problem: The value of iix is dependent on the values of the arrays $indexx$ and $ixoffset$ and cannot be guaranteed to be different for each iteration

- Solution: Remove the data dependent element to a non-parallelized loop; thus creating a parallel and a non-parallel loop

Indirect Indexing

```
for (i=0;i<n;i++) {
  ix=indexx[i];
  iix[i]=ixoffset[ix];
}
for (i=0;i<n;i++) {
  total[iix[i]]=total[iix[i]]+delta;
}
```

Sum Reduction

- Code fragment:

```
total=0.0
for(i=0;i<n;i++) {
  total+=a[i];
}
```

- Problem: Value of total is carried over from iteration to iteration
- Solution: Create local sub_total variables for each processor and do a global sum at the end

Sum Reduction

```
float *a,total;
int n;

void parallel_func() {
  int i,id,nprocs;
  float sub_total;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  sub_total=0.0;
  for (i=id;i<n;i+=nprocs) {
    sub_total+=a[i];
  }

  m_lock();
    total+=sub_total;
  m_unlock();
}
```

False Reduction Dependence

- Code fragment:

```
for (i=0;i<n;i++) {
  total=0.0;
  for (j=0;j<m;j++) {
    total+=a[i][j];
  }
  b[i]=c[i]*total;
}
```

- Reduction in inner loop tempts one to parallelize it; however, a better scheme is to make $total$ local and parallelize the outer loop

Recurrence

- Code fragment:

```
for (i=0;i<n;i++) {
  a[i]=a[i-1]+b[i];
}
```

- Problem: Computation of a depends on value in previous iterations

- Solution: No easy transformation, special algorithms exist for solving recurrences in parallel

Stride Not 1

- Code fragment:

```
for (i=0;i<n;i+=2) {
  a[i]=a[i-1]+b[i];
}
```

- Recurrence example with non-unit stride removes the dependence and makes the loop parallel

Loop Reordering

- Code fragment:

```
for (k=0;k<n;k++) {
  for (i=0;i<n;i++) {
    for (j=0;j<n;j++) {
      a[i][j]+=b[i][k]+c[k][j];
    }
  }
}
```

- Outer loop cannot be parallelized due to dependence carried on a. Can parallelize i loop, but very little work inside the parallel loop

- Interchanging k and i loops does not alter program semantics; however, parallelizing the outer i loop creates more work inside the parallel loop

Loop Reordering

```
float *a,*b,*c;

void parallel_func() {
  int i,id,nprocs;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  for (i=id;i<n;i+=nprocs) {
    for (k=0;k<n;i++) {
      for (j=0;j<n;j++) {
        a[i][j]+=b[i][k]+c[k][j];
      }
    }
  }
}
```

Loop Distribution

- Code fragment:

```
for (i=1;i<n;i++) {
  a[i]=b[i]+c[i]*d;
  c[i]=a[i-1];
}
```

- Problem: Dependence carried on a

- Solution: Distribute loop into two loops, both are now i parallelizable

Loop Distribution

```
float *a,*b,*c,d;
int n;

void parallel_func() {
  int i,id,nprocs,start;

  id=m_get_myid();
  nprocs=m_get_numprocs();
  if (id==0) start=nprocs;
  else start=id;

  for (i=start;i<n;i+=nprocs) {
    a[i]=b[i]+c[i]*d;
  }
  m_barrier();
  for (i=start;i<n;i+=nprocs) {
    c[i]=a[i-1];
  }
}
```

Summary

- Loop scheduling
- Loop Parallelization
- NEXT LECTURE: Shared Memory Parallel Programming Examples