Distributed Systems (COMP9243)

Lecture 3b: Distributed Shared Memory

① DSM

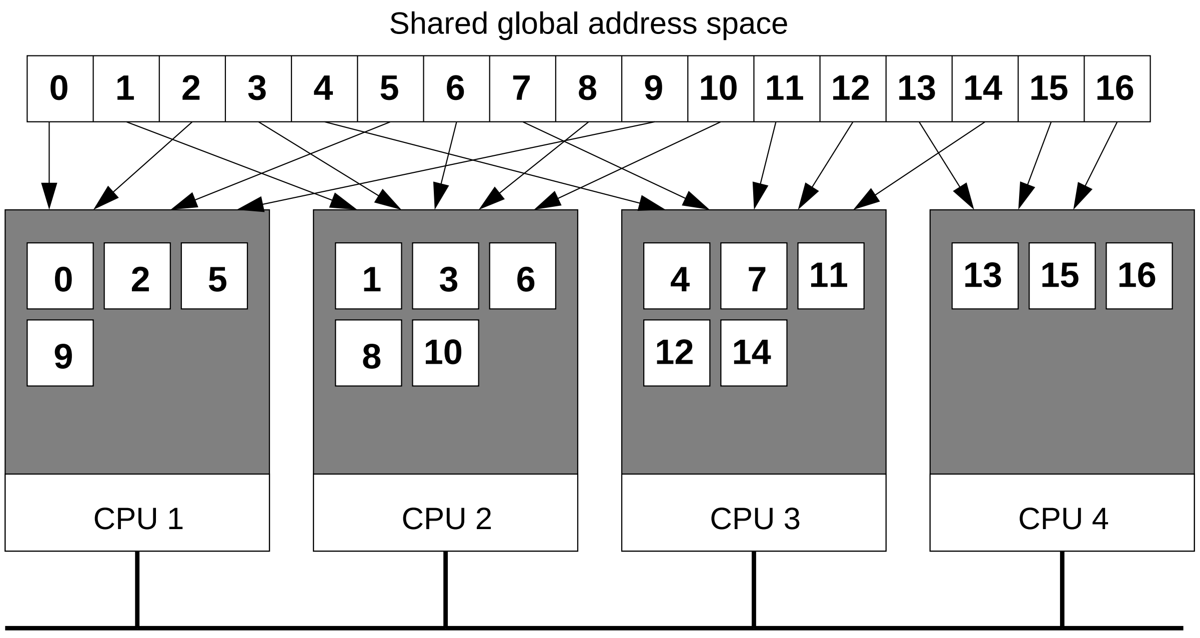
② Case study

③ Design issues

④ Implementation issues

Distributed Shared Memory (DSM)

DSM: shared memory + multicomputer



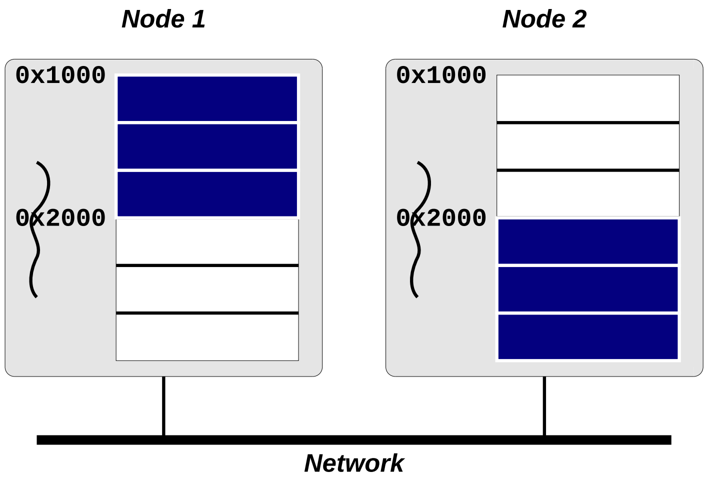
SHARED ADDRESS SPACE

DSM consists of two components:

① Shared address space

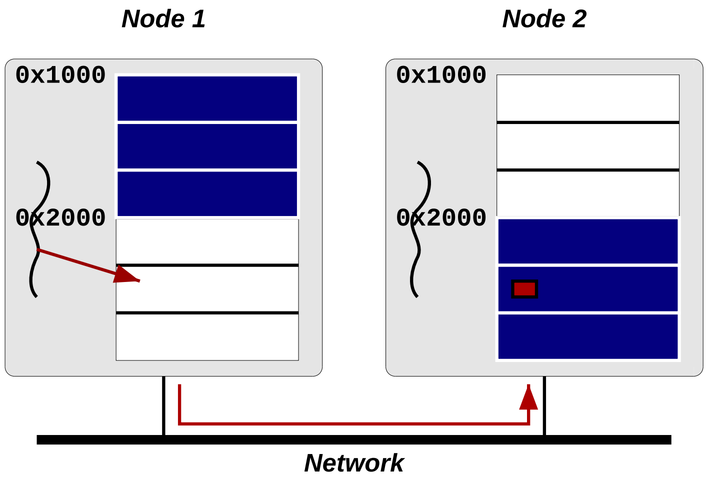
② Replication and consistency of memory objects

Shared address space:



➜ Shared addresses are valid in all processes

Transparent remote access:



Properties:

- ➜ Remote access is expensive compared to local memory access
- ➜ Individual operations can have very low overhead
- ➜ Threads can distinguish between local and remote access

Why DSM?:

- ➜ Shared memory model: easiest to program to
- ➜ Physical shared memory not possible on multicomputer
- ➜ DSM emulates shared memory

Benefits of DSM:

- ➜ Ease of programming (shared memory model)
- ➜ Eases porting of existing code
- ➜ Pointer handling
  - Shared pointers refer to shared memory
  - Share complex data (lists, etc.)
- ➜ No marshalling

DSM IMPLEMENTATIONS

Hardware:

- ➜ Multiprocessor
- ➜ Example: MIT Alewife, DASH

OS with hardware support:

- ➜ SCI network cards (SCI = Scalable Coherent Interconnect)
- ➜ SCI maps extended physical address space to remote nodes
- ➜ OS maps shared virtual address space to SCI range

OS and Virtual Memory:

- ➜ Virtual memory (page faults, paging)
- ➜ Local address space vs Large address space

Middleware:

➜ Library:

- Library routines to create/access shared memory
- Example: MPI-2, CRL

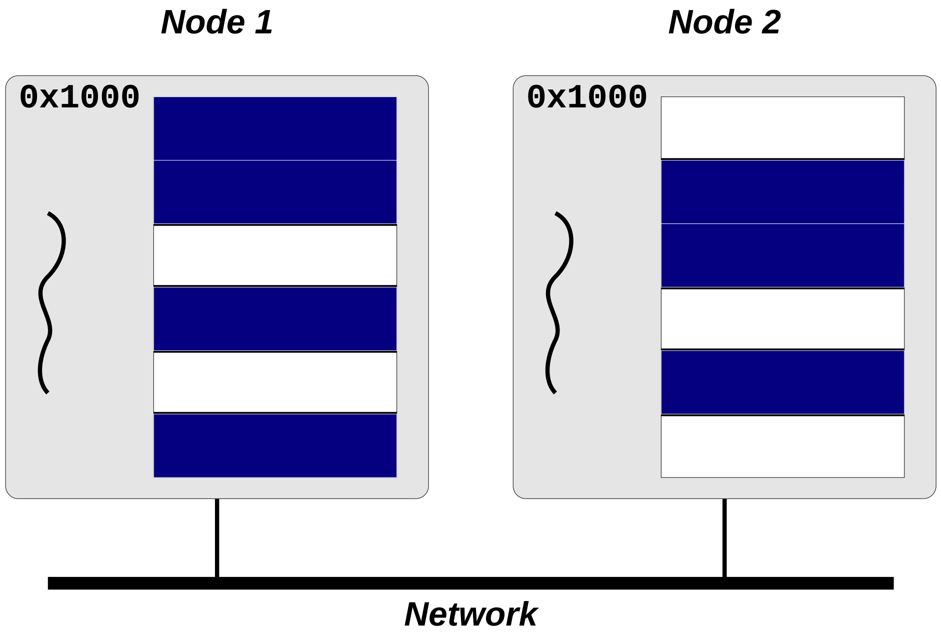
➜ Language

- Shared memory encapsulated in language constructs
- Extend language with annotations
- Example: Orca, Linda, JavaSpaces, JavaParty, Jackal

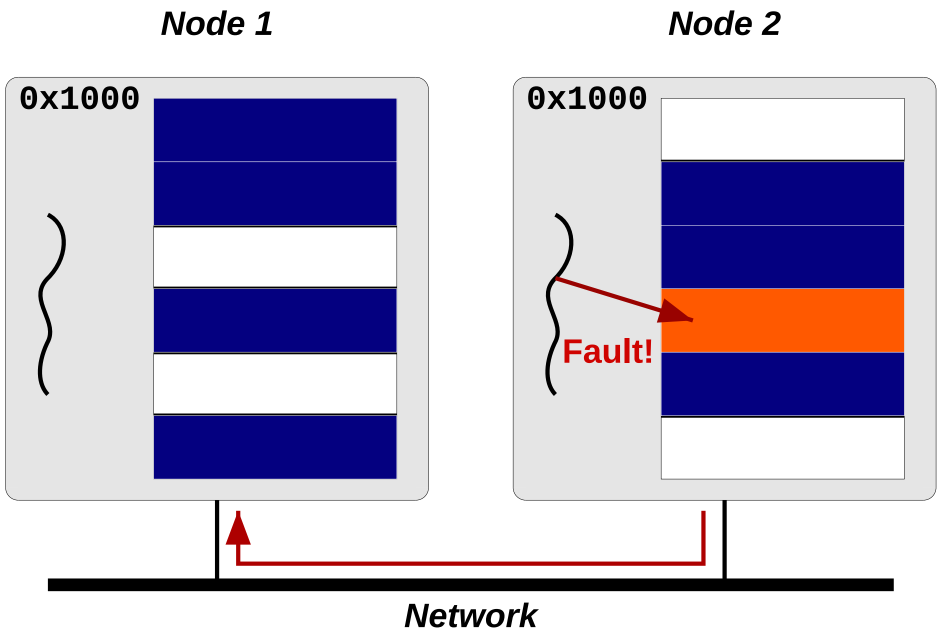
Typical Implementation:

- ➜ Most often implemented in user space (e.g., TreadMarks, CVM)
- ➜ User space: what's needed from the kernel?
  - User-level fault handler
    (e.g., Unix signals)
  - User-level VM page mapping and protection
    (e.g., `mmap()` and `mprotect()`)
  - Message passing layer
    (e.g., socket API)

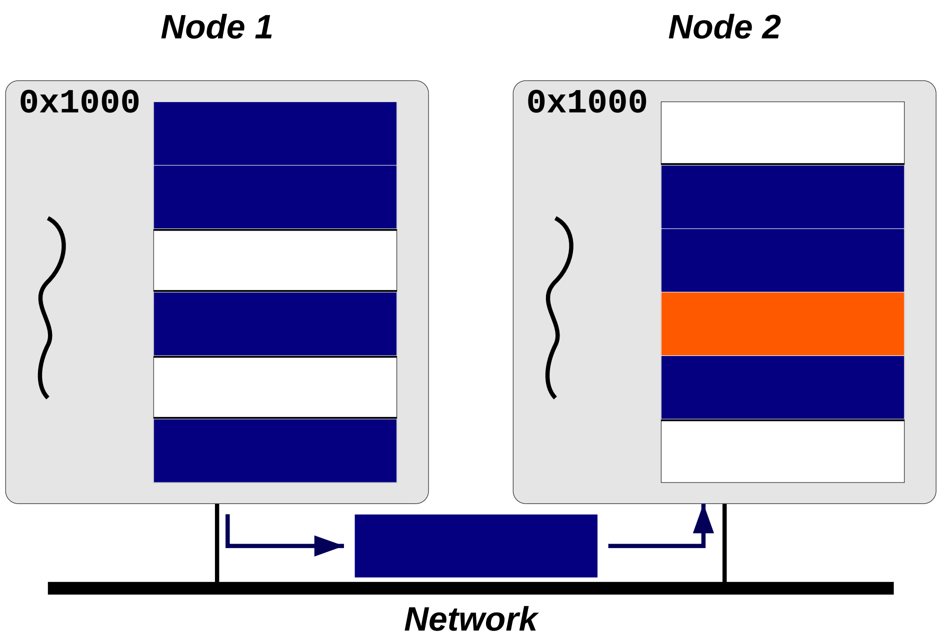
Example: two processes sharing memory pages:



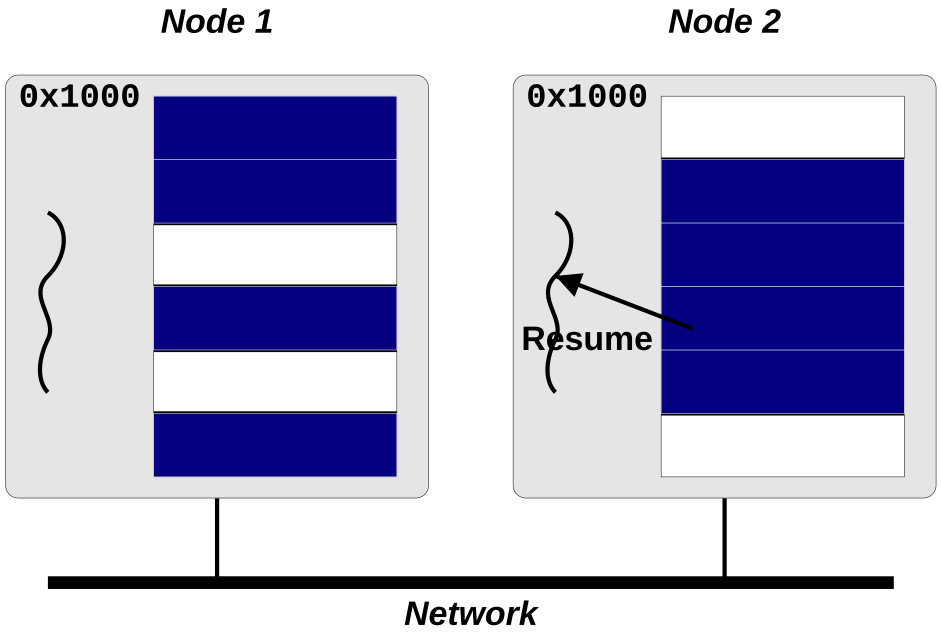
Occurrence of a read fault:



Page migration and replication:



Recovery from read fault:



DSM Models

Shared page (coarse-grained):

- ➜ Traditional model
- ➜ Ideal page size?
- ✗ False sharing
- ➜ Examples: Ivy, TreadMarks

Shared region (fine-grained):

- ➜ More fine grained than sharing pages
- ☑ Prevent false sharing
- ✗ Not regular memory access (transparency)
- ➜ Examples: CRL (C Region Library), MPI-2 one-sided communication, Shasta

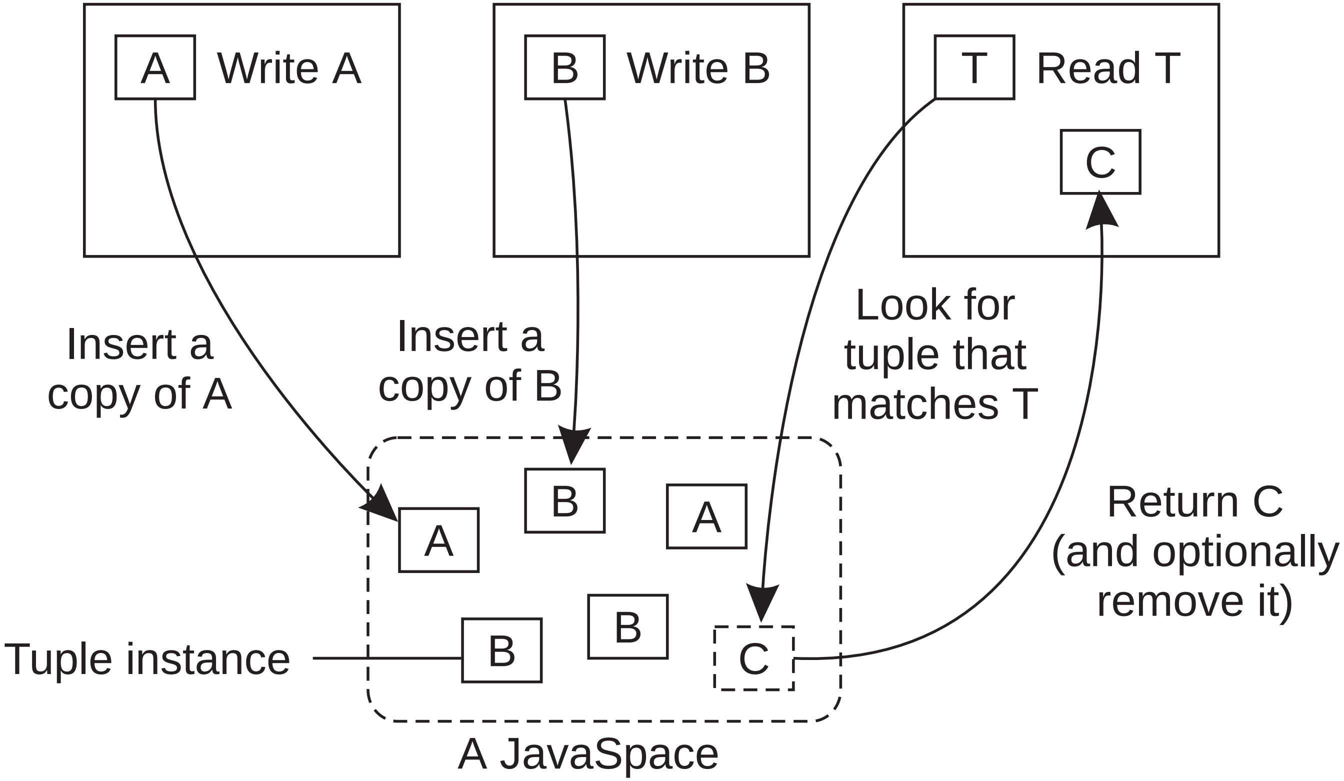
Shared variable:

- ➜ Release and Entry based consistency
- ➜ Annotations
- ☑ Fine grained
- ✗ More complex for programmer
- ➜ Examples: Munin, Midway

Shared structure:

- ➜ Encapsulate shared data
- ➜ Access only through predefined procedures (e.g., methods)
- ☑ Tightly integrated synchronisation
- ☑ Encapsulate (hide) consistency model
- ✗ Lose familiar shared memory model
- ➜ Examples: Orca (shared object), Linda (tuple space)

Tuple Space:


A
Write A
B
Write B
T
Read T
C
Insert a copy of A
Insert a copy of B
Look for tuple that matches T
Return C (and optionally remove it)
Tuple instance
A
B
A
B
B
C
A JavaSpace

LINDA EXAMPLE

```
main() {
  ...
  eval("function", f()) ;
  eval("function", f()) ;
  ...
  for (i=0; i<100; i++)
    out("data", i) ;
  ...
}
f(){
  in("data", ?x) ;
  y = g(x) ;
  out("function", x, y) ;
}
```

What's good about this?

Applications of DSM

- ➜ Scientific parallel computing
  - Bioinformatics (gene sequence analysis)
  - Simulations (climate modeling, economic modeling)
  - Data processing (physics, astronomy)
- ➜ Graphics (image processing, rendering)
- ➜ Data server (distributed FS, Web server)
- ➜ Data storage

DSM ENVIRONMENTS

➜ Multiprocessor
  - NUMA

➜ Multicomputer
  - Supercomputer
  - Cluster
  - Network of Workstations
  - Wide-area

Requirements of DSM

Transparency:

- ➜ Location, migration, replication, concurrency

Reliability:

- ➜ Computations depend on availability of data

Performance:

- ➜ Important in high-performance computing
- ➜ Important for transparency

Scalability:

- ➜ Important in wide-area
- ➜ Important for large computations

Consistency:

- ➜ Access to DSM should be consistent
- ➜ According to a consistency model

Programmability:

- ➜ Easy to program
- ➜ Communication transparency

CASE STUDY

TreadMarks:

- ➜ 1992 Rice University
- ➜ Page based DSM library
- ➜ C, C++, Java, Fortran
- ➜ Lazy release consistency model
- ➜ Heterogeneous environment

Design Issues

Granularity

- ➜ Page based, Page size: minimum system page size

Replication

- ➜ Lazy release consistency

Scalability

- ➜ Meant for cluster or NOW (Network of Workstations)

Synchronisation primitives

- ➜ Locks (acquire and release), Barrier

Heterogeneity

- ➜ Limited (doesn't address endianness or mismatched word sizes)

Fault Tolerance

- ➜ Research

No Security

USING TREADMARKS

Compiling:

- Compile
- Link with TreadMarks libraries

Starting a TreadMarks Application:

```
app -- -h host1 -h host2 -h host3 -h host4
```

Anatomy of a TreadMarks Program:

- Starting remote processes

```
Tmk_startup(argc, argv);
```

- Allocating and sharing memory

```
shared = (struct shared*) Tmk_Malloc(sizeof(shared));
Tmk_distribute(&shared, sizeof(shared));
```

- Barriers

```
Tmk_barrier(0);
```

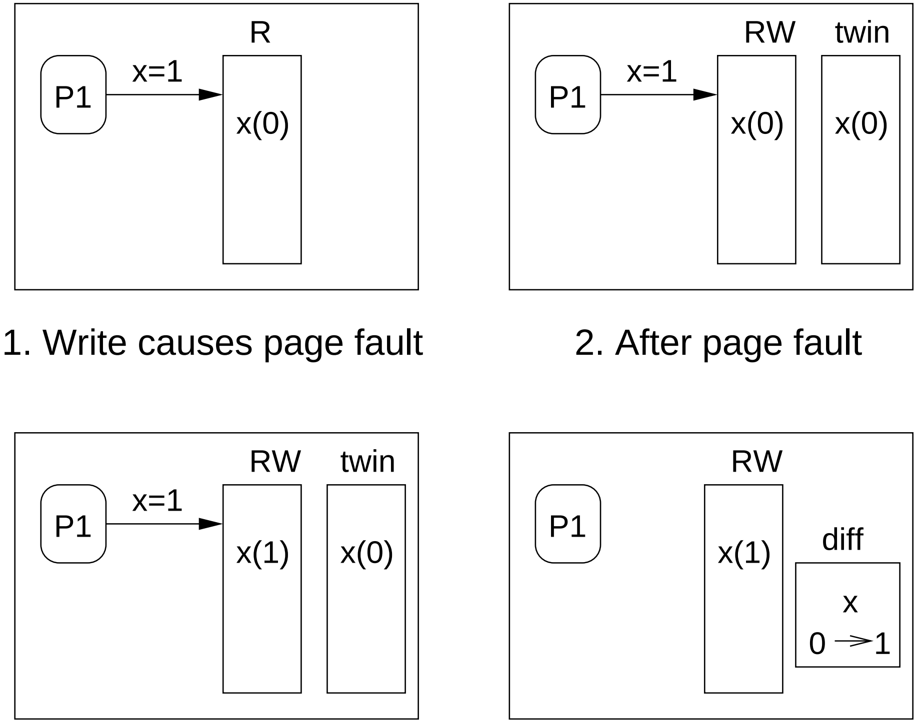
- Acquire/Release

```
Tmk_lock_acquire(0);
shared->sum += mySum;
Tmk_lock_release(0);
```

TreadMarks Implementation

Consistency Protocol:

- ➜ Multiple writer
- ➜ Twins
- ➜ Reduce false sharing



1. Write causes page fault
2. After page fault
3. Write is executed
4. At release or barrier

Update Propagation:

- ➜ Modified pages invalidated at acquire
- ➜ Page is updated at access time
- ➜ Updates are transferred as diffs

Lazy Diffs:

- ➜ Normally make diffs at release time
- ➜ Lazy: make diffs only when they are requested

Communication:

- ➜ UDP/IP or AAL3/4 (ATM)
- ➜ Light-weight, user-level protocols to ensure message delivery
- ➜ Use `SIGIO` for message receive notification

Data Location:

- ➜ Know who has diffs because of invalidations
- ➜ Each page has a statically assigned manager

Modification Detection:

- ➜ Page Fault
- ➜ If page is read-only then do consistency protocol
- ➜ If not in local memory, get from manager

Memory Management:

- ➜ Garbage collection of diffs

Initialisation:

- ➜ Processes set up communication channels between themselves
- ➜ Register `SIGIO` handler for communication
- ➜ Allocate large block of memory
  - Same (virtual) address on each machine
  - Mark as non-accessible
  - Assign manager process for each page, lock, barrier (round robin)
- ➜ Register `SEGV` handler

Reading List

Distributed Shared Memory: A Survey of Issues and Algorithms

An overview of DSM and key issues as well as older DSM implementations.

TreadMarks: Shared Memory Computing on Networks of Workstations

An overview of TreadMarks, design decisions and implementation.

HOMEWORK

Do Assignment 1!